

External Corrosion Control of On-Grade Carbon Steel Storage Tank Bottoms

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Foreword

Sustaining long-term leak-free operation of aboveground storage tank (AST) bottoms is an extremely important goal of all AST owners and operators. Mitigation of corrosion on the external side of on-grade carbon steel tank bottoms is a principal element necessary to achieve this goal.

Scope

This standard provides a comprehensive compilation of corrosion mitigation considerations, practices, and procedures for AST bottoms. It is applicable from tank construction through long-term integrity management and maintenance processes. It presents supplements and alternatives to cathodic protection (CP). A broad section on vapor corrosion inhibitor (VCI) practices and procedures for mitigation of external tank bottom corrosion is included.

Rationale

Attainment of low tank bottom maintenance costs and leak-free AST bottom operation over the long term is a function of more than just the implementation of external corrosion control systems. This standard practice provides industry guidance on a variety of important corrosion mitigation practices to consider during AST engineering and construction, as well as during the operational phase.

Referenced Standards and Other Consensus Documents

The latest edition, revision, or amendment of the referenced standards in effect shall govern unless otherwise dated.

AMPP/NACE/SSPC, www.ampp.org:

NACE TM0304	Offshore Platform Atmospheric and Splash Zone Maintenance Coating System Evaluation
NACE No. 2/SSPC-SP 10	Near-White Metal Blast Cleaning
NACE SP0193	External Cathodic Protection of On-Grade Carbon Steel Storage Tank Bottoms
NACE SP0775	Preparation, Installation, Analysis, and Interpretation of Corrosion Coupons in Oilfield Operations
SSPC-PA 2	Procedure for Determining Conformance to Dry Coating Thickness Requirements
SSPC-SP 2	Hand Tool Cleaning

American Petroleum Institute (API), www.api.org:

API 650	Welded Tanks for Oil Storage
API 651	Cathodic Protection of Aboveground Petroleum Storage Tanks
API 653	Tank Inspection, Repair, Alteration, and Reconstruction

ASTM International, www.astm.org:

ASTM G95	Standard Test Method for Cathodic Disbondment Test of Pipeline Coatings (Attached Cell Method)
ASTM G14	Standard Test Method for Impact Resistance of Pipeline Coatings (Falling Weight Test)
ASTM D4541	Standard Test Method for Pull-Off Strength of Coatings Using Portable Adhesion Testers

ASTM G57	Standard Test Method for Measurement of Soil Resistivity Using the Wenner Four-Electrode Method
ASTM G51	Standard Test Method for Measuring pH of Soil for Use in Corrosion Testing
ASTM D516	Standard Test Method for Sulfate Ion in Water
ASTM C778	Standard Specification for Standard Sand
ASTM C144	Standard Specification for Aggregate for Masonry Mortar
Environmental Protection Agency (EPA), www.epa.gov:	
EPA 0376.1	Sulfide – Titrimetric, Iodine
International Organization for Standardization (ISO), www.iso.org:	
ISO 31000	Risk Management - Principles and Guidelines

In AMPP standards, the terms *shall* and *must* are used to state requirements and are considered mandatory. The term *should* is used to state something that is recommended, but is not considered mandatory. The term *may* is used to state something considered optional.

Section 1: General

- 1.1 This standard has been developed to specifically address corrosion monitoring and control beyond CP for the external side of AST bottoms. Guidance is provided for the use of other corrosion control technologies with an emphasis on VCI applications.
- 1.2 The provisions of this standard are intended to be applied under the direction of a competent person who, by reason of knowledge of the physical sciences and principles of engineering and mathematics, acquired by education and related practical experience is qualified to engage in the practice of AST external bottom corrosion control.
- 1.3 Descriptions of many factors that contribute to external corrosion of the tank bottom plates are provided as well as guidance on monitoring of the tank pad electrolyte in contact with the tank bottom.
- 1.4 This standard is applicable to welded, bolted, and riveted carbon steel ASTs that are field or shop-fabricated and constructed on-grade.
- 1.5 Corrosion mitigation guidance is provided relative to the external side of AST bottoms. Internal product-side tank bottom corrosion mitigation is not included in this standard.
- 1.6 Limited CP details and guidance are included in this standard. For additional AST CP guidance, see NACE SP0193.
- 1.7 An important focus of this standard is to welcome and encourage the consideration of new applicable products, technologies, and processes for inclusion during future standard reviews/revisions.

Section 2: Definitions

Aboveground Storage Tank (AST): A stationary container of greater than 500-barrel capacity usually cylindrical in shape, consisting of a metallic roof, shell, bottom, and support structure where more than 90 percent of the tank volume is above surface grade.

Amphoteric Metal: A metal that is susceptible to corrosion in both acid and alkaline environments.

Anode: The electrode of an electrochemical cell at which oxidation occurs. (Electrons flow away from the anode in the external circuit. Corrosion usually occurs and metal ions enter solution at the anode).

Anodic Polarization: (1) The change of the electrode potential in the noble (positive) direction caused by current across the electrode/electrolyte interface. (2) A forced noble (positive) shift in electrode potential (See *Polarization*).

Cathode: The electrode of an electrochemical cell at which reduction is the principal reaction. (Electrons flow toward the cathode in the external circuit).

Cathodic Polarization: (1) The change of electrode potential in the active (negative) direction caused by current across the electrode/electrolyte interface. (2) A forced active (negative) shift in electrode potential. (See *Polarization*).

Cathodic Protection: A technique to reduce the corrosion of a metal surface by making that surface the cathode of an electrochemical cell.

Coating: (1) A liquid, liquefiable, or mastic composition that, after application to a surface, is converted into a solid protective, decorative, or functional adherent film. (2) A thin layer of solid material on a surface that provides improved protective, decorative, or functional properties.

Corrosion: The deterioration of a material, usually a metal, that results from a reaction with its environment.

Corrosion Coupon: A weighed sample (coupon) of the metal or alloy under consideration is introduced into the process, and later removed after a reasonable time interval. The coupon is then cleaned of all corrosion products and is reweighed. The weight loss is converted to a total thickness loss or average corrosion rate.

Corrosion Rate: The time rate of change of corrosion. (It is typically expressed as mass loss per unit area per unit time, penetration per unit time, etc.).

Criterion: Standard for assessment of the effectiveness of a CP system.

Current Density: The electric current flowing to or from a unit area of an electrode surface.

Electrical Resistance (ER) Probe: A corrosion growth rate/metal loss measurement probe that is based on the principle of increase in resistance of a metal strip or wire as a function of metal loss due to reduction in the cross-sectional area of the probe element. It indicates the cumulative metal loss of the element.

Electrode: A material that conducts electrons, is used to establish contact with an electrolyte, and through which current is transferred to or from an electrolyte.

Electrolyte: A chemical substance containing ions that migrate in an electric field. For the purposes of this standard, electrolyte refers to the soil or liquid adjacent to and in contact with the external side of an AST bottom.

External Side: The external surface of the product containment bottom in contact with the tank pad.

IR Drop: The voltage across a resistance when current is applied in accordance with Ohm's law.

Polarization: The change from the corrosion potential because of current flow across the electrode/electrolyte interface.

Polarized Potential: (1) (general use) The potential across the electrode/electrolyte interface that is the sum of the corrosion potential and the applied polarization. (2) (CP use) The potential across the structure/electrolyte interface that is the sum of the corrosion potential and the cathodic polarization.

Reference Electrode: An electrode having a stable and reproducible potential, which is used in the measurement of other electrode potentials.

Secondary Containment: A device or system used to control the accidental escape of a stored product so it may be properly recovered or removed from the environment. For the purpose of this standard, secondary containment refers to an impermeable membrane.

Tank Pad: The material immediately adjacent to the exterior steel bottom of an aboveground storage tank.

Vapor Corrosion Inhibitors (VCI): Sometimes referred to as “Volatile Corrosion Inhibitors.” Substances that slowly release a corrosion-preventative compound into an enclosed air space, effectively protecting exposed metal surfaces.

VCI Specialist: A competent person who, by reason of knowledge of the physical sciences and principles of engineering and mathematics, acquired by education and related practical experience is qualified to engage in the practice of AST corrosion control through the application of VCI products and technologies.

NOTE: Such persons may be but are not limited to, persons acknowledged as VCI Specialists by VCI manufacturers if their professional activities include suitable experience in AST corrosion control through the application of VCI products and technologies.

Voltage: An electromotive force or a difference in electrode potentials expressed in volts.

Section 3: External Corrosion of Aboveground Steel Storage Tank Bottoms

3.1 Introduction

3.1.1 The external side of aboveground storage tank bottoms is typically bare steel with mill scale. The bare steel surface is in contact with the tank pad materials installed during tank construction. Therefore, the steel is susceptible to corrosion for the life of the bottom.

3.1.2 Corrosion of the steel bottom plates results from an electrochemical process. There are certain conditions that need to be present for the electrochemical process to function and for corrosion cells to develop. The elements that are common to all corrosion cells are:

3.1.2.1 An anode where oxidation and metal loss occur.

3.1.2.2 A cathode where reduction and protective effects occur.

3.1.2.3 Metallic and electrolytic paths between the anode and cathode through which the electronic and ionic current flows.

3.1.3 External corrosion of AST bottoms occurs in numerous forms. The most common types of corrosion experienced on tank bottoms are generalized surface corrosion and localized (pitting) corrosion.

3.1.3.1 The general surface corrosion of bare steel includes thousands of microscopic corrosion cells occurring on the metal surface. This typically results in relatively uniform metal loss.

3.1.3.2 Pitting corrosion is a localized form of corrosion by which “pits” or “holes” are produced in the tank bottom plates.

3.2 Corrosion Mechanisms

3.2.1 Dissimilar Metal Corrosion

3.2.1.1 This type of corrosion occurs when two dissimilar metals with different electrical potentials are connected in such a way as to be electrically continuous and in contact with a common electrolyte.

3.2.2 The most significant factors impacting corrosion rates are:

3.2.2.1 The current flow between the dissimilar metals when coupled together.

3.2.2.2 The relative surface areas of the cathode and anode.

3.2.2.3 The temperature of products contained in the tank.

3.2.3 Corrosion tends to be more severe when the anodic area is small with respect to the cathode surface area and the two metals have large natural voltage differences as identified in the Galvanic Series of Metals.

3.2.4 As an example, this type of corrosion may occur on carbon steel tank bottom locations connected to underground metals that are cathodic to carbon steel such as stainless steel or copper.

3.2.5 The metal composition is also a factor in determining areas on a metal surface that become anodic. Differences in electrochemical potential between adjacent areas can result from uneven distribution of alloying elements or contaminants within the metal structure. Corrosion may also be caused by differences between weld metal, heat-affected zone, and parent metal.

3.3 Dissimilar Soils Corrosion

3.3.1 Tank bottom corrosion is substantially affected by the electrolyte in contact with the steel surface. Corrosion rates are likely to increase if the electrolyte is not uniformly consistent and is contaminated with various types of soils, micro-organisms, and other debris.

3.3.2 Dissolved salts in the tank pad increase the current carrying capacity of the soil electrolyte and affect reaction rates at the anodic and cathodic areas.

3.3.3 Microbiologically Influenced Corrosion (MIC) is the result of the metabolic activity of micro-organisms contained in the sand electrolyte in contact with the tank bottom. Severe corrosion may occur if conditions support accelerated MIC growth.

3.3.4 Moisture content, pH, oxygen concentration, and other factors also interact in a complex fashion to influence corrosion.

3.4 Differential Oxygen Concentration Corrosion Cells

3.4.1 It is common for tank bottoms to experience differing oxygen concentrations over the large surface areas.

3.4.2 The differential oxygen concentrations between areas on a steel surface may generate differences in potential. Areas with higher oxygen concentrations become cathodic, while areas with lower oxygen concentrations become anodic and corrode.

3.5 Important Engineering Considerations Affecting External Tank Bottom Corrosion

Mitigation of external corrosion on tank bottoms should be included in the engineering process of new tank construction, or as part of a tank bottom repair/replacement plan. Important corrosion mitigation factors include:

- 3.5.1** Tank pad materials.
 - 3.5.1.1** Chemical composition
 - 3.5.1.2** Size of aggregates
 - 3.5.1.3** Electrical resistivity
 - 3.5.1.4** Control of installation practices to prevent contamination of the tank pad.
 - 3.5.1.5** Tank pad compaction to ensure uniform contact between the tank bottom and the tank pad material.
- 3.5.2** Undertank containment liners.
 - 3.5.2.1** Electrical resistivity of the liner materials.
 - 3.5.2.2** Location of the containment liners relative to the tank bottom.
 - 3.5.2.3** Drainage of any accumulated water above the liner.
- 3.5.3** Prevention of water intrusion undertank.
 - 3.5.3.1** Elevation of the underground water table.
 - 3.5.3.2** Tank bottom elevation in relation to surrounding grade.
 - 3.5.3.3** Containment and drainage of rainwater within the tank berm area.
 - 3.5.3.4** Drainage of accumulated water undertank.
- 3.5.4** Type of Service
 - 3.5.4.1** Type of product stored.
 - 3.5.4.2** In-service temperature of tank bottom.
 - 3.5.3.3** Frequency of product fill and discharge.
- 3.5.5** Tank bottom and foundation specifications.
 - 3.5.5.1** Tank bottom material of construction.
 - 3.5.5.2** External tank bottom coating.
 - 3.5.5.3** Type of tank support foundation.

3.6 Increased Rates of Corrosion Due to Elevated Tank Bottom Temperatures

- 3.6.1** Accelerated corrosion can occur on the external side of tank bottoms subjected to elevated temperatures in the presence of moisture.
- 3.6.2** NOTE: The corrosion rate of steel may double with every 18 °F (10 °C) increase in temperature above 77 °F (25 °C).
- 3.6.3** ASTs containing products above ambient temperature may require an increase in CP design current density to achieve adequate corrosion protection on the external surface of the bottom.

- 3.6.4** Corrosion rate probes may assist in the evaluation of corrosion rates within an elevated temperature tank pad electrolyte.
- 3.6.5** Elevated tank bottom temperatures may also dry out tank pad materials, resulting in a significant increase in electrolyte resistivity and a reduction in effectiveness of corrosion mitigation systems such as CP or VCIs.

Section 4: Tank Pad Specifications and Installation Practices

4.1 Introduction

- 4.1.1** Different types of sand pad materials are used for aboveground storage tanks due to a wide variety of surface, subsurface, and climatic conditions.
- 4.1.2** The pad material under the tank bottom has a significant effect on external corrosion of the tank bottom and can influence the effectiveness and applicability of engineered systems for corrosion mitigation.
- 4.1.3** There are a wide variety of tank pad materials available, some of which may impede the beneficial effects of CP or other engineered systems for corrosion mitigation.
- 4.1.4** A competent person should review the tank pad specifications and installation procedures prior to the construction of the respective tank to determine which engineered systems for corrosion mitigation would help preserve the integrity of the tank bottom.

4.2 Tank Pad Option

4.2.1 Sand Tank Pad

- 4.2.1.1** Clean washed and graded sand is one of the most common materials used as a pad beneath aboveground storage tank bottoms.
- 4.2.1.2** The use of clean sand alone normally does not eliminate the need for CP or other engineered systems of corrosion mitigation since corrosion may occur due to intrusion of water and other contaminants from rain, snow, shallow water table, or condensation. Guidelines for the chemical and electrical analysis of the sand for corrosive contaminants are discussed in [Paragraph 4.3](#).
- 4.2.1.3** A clean sand tank pad used in conjunction with engineered corrosion mitigation systems is an effective means of protecting the tank bottom from external corrosion.

4.2.2 Continuous Concrete Tank Pad

- 4.2.2.1** A properly designed concrete tank pad constructed on stable, adequately prepared subsoil may be effective in eliminating intrusion of groundwater and mitigating external tank bottom corrosion.
- 4.2.2.2** The surface of the concrete tank pad and steel bottom plate should be kept free of contaminants during construction.
- 4.2.2.3** Preparation of a stable soil to support the concrete slab is essential to ensure the continued integrity of the pad. Unstable soil may induce cracks in the slab through which water and contaminants may permeate to the steel tank bottom and provide a corrosive environment.

- 4.2.2.4** Although corrosion from the soil may be mitigated by a concrete pad, there may still be a collection of moisture between the tank bottom and the tank pad due to condensation, blowing rain or snow, flooding due to inadequate drainage, or rainwater from the roof of the tank flowing down the tank walls. Corrosion may occur due to this moisture accumulation.
- 4.2.2.5** CP is generally not considered an effective way to combat the external side corrosion mechanisms associated with continuous concrete tank pad foundations. The high resistivity of the concrete severely restricts CP system current flow to the tank bottom.
- 4.2.2.6** A free-draining concrete tank pad and a seal around the periphery of the tank may be effective in eliminating the accumulation of moisture between the pad and the tank bottom where flooding in the dike area above the tank bottom does not occur.
- 4.2.2.7** In situations where water may condense on the tank bottom, or water is retained above the concrete pad, accelerated corrosion may occur.
- 4.2.2.8** Numerous complex factors affect tank bottom underside corrosion in the presence of concrete. Prediction of the propensity of corrosion in this case is difficult. Thus, care should be observed with tanks on concrete pads since CP is likely to be ineffective, although other corrosion mitigation methods such as VCI chemistry may be considered.

4.2.3 Crushed Limestone or Clam Shell Tank Pad

- 4.2.3.1** Layers of crushed limestone or clam shells have been used instead of sand for a tank pad in some locations.
- 4.2.3.2** Such tank pads with and without the use of CP have produced mixed soil-side corrosion mitigation results.
- 4.2.3.3** The tank pad should be fine and uniform, since differential aeration corrosion cells can cause pitting at contact areas between the large particles and the metal.
- 4.2.3.4** The intrusion of water from rain or groundwater makes the environment under the tank alkaline, which may reduce corrosion. However, if contaminants are present in the pad, or with time infiltrate the pad, corrosion may accelerate.
- 4.2.3.5** The use of crushed limestone or clam shells does not eliminate the need for CP or other engineered systems of corrosion mitigation.
- 4.2.3.6** A steel retaining ring is sometimes installed at a sufficient distance from the tank shell to ensure berm stability. The ring shall not impede the drainage of water away from the tank.
- 4.2.3.7** For new tank construction, the use of a crushed limestone or clamshell tank pad is discouraged.

4.2.4 Oiled Sand Tank Pad

- 4.2.4.1** Oil has been mixed with sand during tank pad construction in some locations for various reasons, including compaction and corrosion control. Because severe tank bottom external side corrosion has been routinely experienced with these tank pad materials, tank pads should not be constructed of oiled sand.

4.2.5 Continuous Asphalt Tank Pad

- 4.2.5.1** A tank pad of new asphalt may provide similar advantages and disadvantages as a concrete pad for reducing corrosion and eliminating the need for CP.
- 4.2.5.2** The asphalt pad should be constructed with a cone-up surface grade to ensure drainage of water from under the tank bottom.
- 4.2.5.3** Consideration should be given to tanks that routinely contain elevated-temperature products. High temperatures may cause accelerated degradation of the asphalt tank pad.
- 4.2.5.4** Asphalt generally degrades with time and may provide a path for water and dissolved contaminants to come into contact with the steel tank bottom, allowing corrosion to occur.
- 4.2.5.5** Due to the dielectric properties of asphalt, CP is generally not considered an effective way to mitigate the external tank bottom corrosion mechanisms associated with continuous asphalt tank pads.
- 4.2.5.6** The condition of the external surface of the tank bottom as well as the asphalt may be determined if coupons are cut from the tank bottom.
- 4.2.5.7** For new tank construction, use of asphalt tank pads is generally discouraged.

4.2.6 Native Soil Tank Pad

- 4.2.6.1** Compacted native soil is sometimes used as a tank pad.
- 4.2.6.2** The native soil is usually not homogenous and may lead to accelerated corrosion as a result of the varying levels of oxygen, pH, and chemical composition.
- 4.2.6.3** Engineered systems of corrosion mitigation are required to ensure the long-term integrity of the tank bottoms.
- 4.2.6.4** For new tank construction, use of native soil tank pads is highly discouraged.

4.3 Sand Tank Pad Material Specification

- 4.3.1** Soil resistivity may provide information about the corrosivity of the material used under and around a tank. Soil resistivity alone should not be used to determine tank sand pad corrosivity and the requirements for engineered systems of corrosion mitigation.
- 4.3.2** Consideration should also be given to rainwater intrusion onto the tank pad during construction and while the tank is in service.
- 4.3.3** In coastal areas, salt spray on tank surfaces can be washed down the sides of the tank by rain and may flow beneath the tank to contaminate the tank pad. This also may occur in areas where fertilizers or chemicals may be in the atmosphere either from spraying or industrial operations. The tank pad also can become contaminated by wicking action that can draw contaminants such as chlorides up from the water table. Sealing the tank chime from intrusion of contaminants is recommended when this risk is present. Engineered corrosion mitigation systems may be required for these situations, especially if the intrusion source is inaccessible.
- 4.3.4** The use of fine particles can provide a denser pad to help reduce the influx and outflow of oxygen from the perimeter of the tank as it is emptied and filled. If large particle sizes or particles with a large variance in size are used, differential aeration corrosion may result at points where the large

particles or debris contact the steel tank bottom. In this case, engineered systems for corrosion mitigation may not be effective in eliminating corrosion.

- 4.3.5** The sand should be clean, screened, and debris free (i.e., no wood, sticks, vegetation, paper, rocks; clay, silt, or other soil; welding rods or other metallic or non-metallic objects; etc.). Cleaning should be done at the supply source and accomplished by mechanical washing with water that cannot alter the chemical composition or electrical resistance of the sand material. If a municipal potable water supply is used for the washing of the sand, care should be taken to ensure no contaminants are added to the sand pad.
- 4.3.6** Masonry mortar quality sand is sometimes specified for the sand pad material. The sand should conform to specifications such as one of the following: 1) ASTM C778 type "20-30 sand," 2) ASTM C778 "graded sand," 3) ASTM C144, or equivalent.
- 4.3.7** Portland cement, at an approximate 33:1 sand-to-cement ratio, or lime, at an approximate 95:5 sand-to-lime ratio, is sometimes added at the supply source to elevate pH levels and/or to facilitate good compaction.
- 4.3.8** Testing of the sand tank pad material should be conducted at the supply source and at the construction site to determine if the chemical properties are at acceptable levels.
- 4.3.9** If test results do not meet owner/operator specified levels, then additional steps such as rewashing and/or adding Portland cement or lime, or securing another source of sand, may need to be taken. Consideration may also be given to using one or more engineered systems for corrosion mitigation based on the results of the chemical analysis.
- 4.3.10** The following properties should be measured to determine the corrosiveness of the sand tank pad material:
 - 4.3.10.1** Electrical resistivity testing of the sand tank pad material is a commonly used method for determining its corrosivity because it is relatively easy to measure. The resistivity of a soil depends on its chemical properties, moisture content, and temperature. Higher resistivity values are generally associated with being less corrosive.
 - 4.3.10.2** Measuring pH indicates the hydrogen ion content of a soil. Corrosion of steel is fairly independent of pH when it is in the neutral range. The rate of corrosion increases appreciably when pH is acidic and decreases when pH is basic.
 - 4.3.10.3** High levels of chlorides can affect the resistivity of soil, and act as a depolarizing agent which can increase the current requirement for CP of steel. Pitting corrosion on steel may also begin as the chloride levels increase.
 - 4.3.10.4** High sulfate levels frequently indicate high concentrations of organic matter.
 - 4.3.10.5** High sulfide levels may indicate that sulfates have been reduced by bacteria.
 - 4.3.10.6** The desired chemical properties of sand tank pad materials as per API 651 and NACE SP0193 are listed in [Table 1](#).

Table 1
Desired Chemical Properties of Sand Tank Pad Material

Property	Test Method	Value per API 651	Value per NACE SP0193
Electrical Resistivity	ASTM G57	> 10,000 ohm-cm	> 5,000 ohm-cm
pH	ASTM G51	> 8.0	≥ 5.0
Chloride Levels	ASTM D512	< 10 ppm	< 10 ppm
Sulfate Levels	ASTM D516	< 200 ppm	< 200 ppm
Sulfide Levels	EPA 0376.1	< 0.1 ppm	< 0.1 ppm

4.4 Sand Tank Pad Installation Control Practices

- 4.4.1** Debris such as rocks, lumps of clay, welding electrodes, paper, plastic, wood, etc. shall not be allowed to remain in the sand tank pad material during tank bottom construction. The tank pad material particles should be fine and uniform.
- 4.4.2** Care should be taken to use clean mixing, handling, and construction equipment to ensure that the sand tank pad material remains free from foreign matter and debris. Any debris or foreign matter which enters the sand pad during construction should be removed prior to the tank bottom being placed over the sand tank pad.
- 4.4.3** Sand is often installed by loose lifts with the total depth or thickness of the sand pad determined by engineering analysis. The total thickness of the sand tank pad should also be compatible with any engineered system for corrosion mitigation, such as CP or VCI.
- 4.4.4** Mechanical vibratory compaction and rolling is suggested for each layer.
- 4.4.5** Compaction by water flooding is not recommended because the water used to flood the sand tank pad may cause contamination and deterioration of the original chemical and electrical properties of the sand material.
- 4.4.6** The underside of each steel plate to be used for tank bottom construction should be inspected immediately before placement onto the tank pad to ensure any debris that is adhered to the steel plates (e.g., dirt, mud, etc.) is removed and that the plate surface is free from contaminants.
- 4.4.7** Excluding engineered systems for corrosion mitigation and leak detection, the pad shall be completely free of any material other than the specified sand material.
- 4.4.8** Tanks should be built in a manner that allows adequate drainage away from the tank bottom, both during construction and after the tank is placed into operation.
- 4.4.9** A seal at the foundation-to-chime plate interface should be considered to minimize water intrusions. Additionally, any leak detection ports protruding through the tank foundation should be kept closed to further minimize the likelihood of water intrusion.

Section 5: Relevant Corrosion Control Considerations for Tank Foundation and Bottom Construction

5.1 Introduction.

- 5.1.1** Aboveground steel storage tank bottoms and foundations are constructed in different ways depending on many factors such as the purpose of service, operations conditions, tank dimensions, and construction limitations.
- 5.1.2** The design of any corrosion control technique for the bottom's external side shall take into consideration the design and construction factors of the bottom and its foundation.

- 5.1.3 Some modification to tank bottom typical designs may be considered to minimize corrosion risk; increase the efficiency of corrosion control systems or reduce its cost.

5.2 Corrosion Control Considerations for Typical AST Foundation Configurations.

5.2.1 Earth Foundations with Earth-Type Ring Wall

- 5.2.1.1 Earth foundation ring walls are constructed with compacted soil or crushed stones, and usually with declined edges. The earth foundation diameters are always larger than their respective tank diameters to provide the required load-bearing capacity. A larger portion of the tank bottom usually sits on the earth foundation ring wall compared to the concrete ring wall type.
- 5.2.1.2 Earth-type ring walls do not allow a good leveling of the soil under the tank bottom. This may create air gaps and allow water to accumulate beneath the bottom, forming localized corrosion cells.
- 5.2.1.3 Earth-type ring walls' declined edges may limit the use of some CP anode types (ex. ribbon or wire anodes) at the periphery area under the tank bottom, leaving that critical portion of the bottom poorly protected.
- 5.2.1.4 Approximately 2 ft of the tank floor is in contact with the earth foundation ring wall as shown below in Figure 1. This may hinder the ability of a CP system to protect that critical portion of the bottom.
- 5.2.1.5 ASTs supported by earth foundation ring walls require more attention towards the tank bottom periphery area. The potential exposure of the annular plates to a more aggressive corrosive environment and the limitations of the conventional corrosion control systems to mitigate the corrosion risk should be considered.

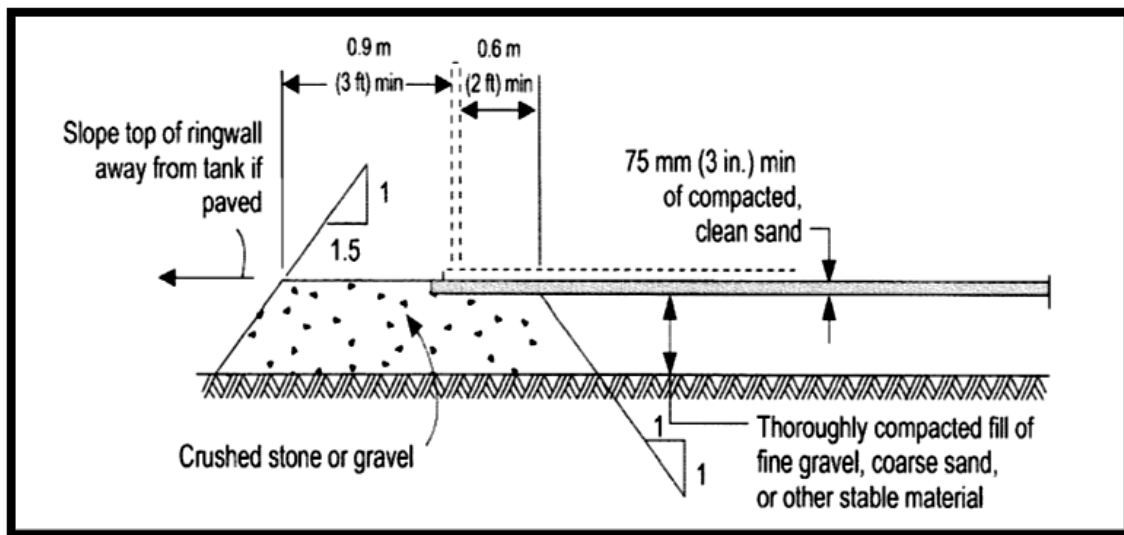


Figure 1: Example of Foundation with Earth-Type Ring Wall

5.2.2 Earth Foundations with Reinforced Concrete Ring

- 5.2.2.1 Reinforced concrete ring wall may be selected to allow more load-bearing capacity for the foundation when the tank's load cannot be held by earth-type foundations.

- 5.2.2.2** Reinforced concrete ring walls allow building of larger, heavier, and taller storage tanks compared to earth foundation ring walls.
- 5.2.2.3** Although concrete ring walls are expected to allow better leveling for the soils under tank bottoms than earth foundations, air gaps, water accumulation, and the resulting corrosion risk may still be a concern requiring special attention by corrosion control systems designers.
- 5.2.2.4** Concrete ring walls require relatively small portions of the tank annular plates to sit directly on them as shown below in Figure 2; this minimizes the periphery critical area and enhances the exposure of the annular plates to the corrosion control systems.
- 5.2.2.5** Concrete ring walls' straight edges allow the installation of CP ribbon or wire anodes in one level. This increases the efficiency of the CP system in providing adequate protection level to the annular plates.
- 5.2.2.6** Concrete ring walls make the sealing of the periphery gap between the tank bottom and the concrete foundation more practical and most effective.
- 5.2.2.7** Tank bottoms supported by concrete ring walls may be subject to a differential settlement of soils under the tank. This may lead to higher bending stress for the annular plates closer to the ring wall.
- 5.2.2.8** In the absence of a proper corrosion control system, corrosion cells between high and low-stressed steel parts may become active. This can lead the stressed plates, annular plates, to be more anodic and susceptible to corrosion.
- 5.2.2.9** Differential settlement may lead to inconsistent contact between the tank bottom plates and the tank pad material. This can lead to the creation of air gaps at some locations under the bottom and may hinder the ability of the CP current to reach the tank bottom external surface.

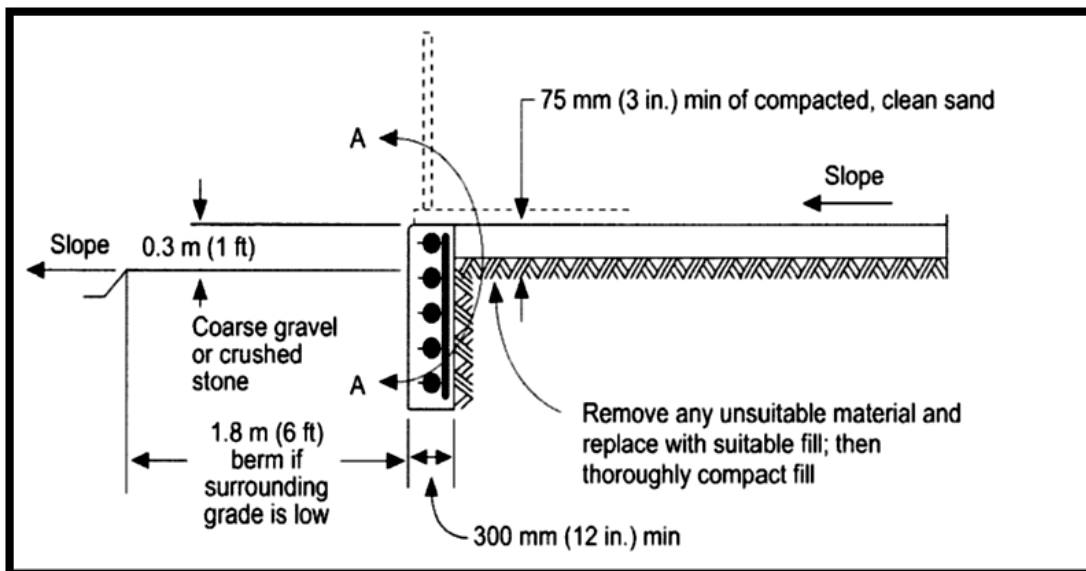


Figure 2: Example of Foundation with Concrete Ring Wall

5.2.3 Reinforced Concrete Continuous Slab Type

- 5.2.3.1** Relatively small tanks may be constructed on a continuous concrete pad. Tank load distribution versus the coating is the main factor governing the selection of such pads by tank designers.
- 5.2.3.2** Concrete tank pads constructed on stable sub-soil may effectively eliminate the corrosion risk caused by underground water.
- 5.2.3.3** Stability of subsoil is mandatory to ensure the integrity of the concrete tank pad; any cracks on the concrete slab may lead to water or contaminant intrusion under the tank, creating a corrosive environment.
- 5.2.3.4** Moisture accumulation between the tank bottom and concrete pad may occur due to water condensation, rain, or snow intrusion.
- 5.2.3.5** Proper sealing for the tank periphery may be effective in reducing the risk of corrosion due to moisture accumulation under the tank bottom.
- 5.2.3.6** CP is not considered an effective corrosion control method for tank external bottoms constructed on concrete pads.

5.2.4 Asphalt Pad Type

- 5.2.4.1** Asphalt pads may provide benefits comparable to concrete pads with a relatively lower cost. The main disadvantage of asphalt pads is their degradation over time, causing cracks to form, even with stable subsoils. Water and contaminants can permeate into the cracks and cause a corrosive environment.
- 5.2.4.2** CP cannot necessarily stop the corrosion started behind the deteriorated asphalt pads; deteriorated asphalt may allow water to accumulate in certain locations while shielding CP current similar to disbonded coating on a pipeline.

5.3 Corrosion Control Considerations for Typical Tank Bottom Types

- 5.3.1** Tank bottoms are constructed in different configurations based on many factors such as operational requirements, environmental considerations, and construction limitations.

5.3.2 Cone Up Bottoms

- 5.3.2.1** Cone-up is a common bottom configuration. It is used to allow better product drainage and removal of accumulated water, wet sludge, and/or excessive fines.
- 5.3.2.2** The shape of the cone-up bottoms minimizes water accumulation under the tank center and moves water away from the tank bottom.
- 5.3.2.3** Cone-up bottoms increase the efficiency of VCIs by allowing better trapping of vapors under tank bottoms.
- 5.3.2.4** Air gaps under cone-up-shaped bottoms may be increased due to the difficulty of the perfect alignment of soil or pad materials with the cone-up-shaped bottom.

5.3.3 Cone Down Bottoms

- 5.3.3.1** Cone-down bottoms are mainly constructed when the tank is required to be filled and emptied regularly during the operational cycle.

5.3.3.2 In terms of corrosion control considerations, a disadvantage of cone-down-shaped bottoms is the possibility of water accumulation under the middle of the tank. This may increase the concentration of chlorides or any contaminants near the tank's center.

5.3.3.3 If VCIs have been selected to control the external side corrosion of a cone-down-shaped tank bottom, the periphery gap between the tank shell and the foundation shall be sealed effectively to maintain the efficiency of the VCIs.

5.3.3.4 The design of CP anode systems under cone-shaped bottoms shall take into consideration the minimum and maximum spacing between the anode and tank bottom.

5.3.4 Single Flat Bottoms

5.3.4.1 A single flat bottom is another tank configuration. It may be constructed with or without a slope based on the operation requirements.

5.3.4.2 Annular plates of non-sloped flat bottoms are subject to water accumulation and accordingly higher corrosion risk.

5.3.4.3 For sloped flat bottoms, the water accumulation and corrosion risk are most likely at the lowest elevation point.

5.3.4.4 Flat bottoms may require sealing in conjunction with VCIs to maintain the vapor under the bottom.

5.3.5 Double Bottoms

5.3.5.1 In a double bottom AST configuration, the upper bottom is called the primary bottom, and the lower bottom is the secondary bottom as shown below in Figure 3.

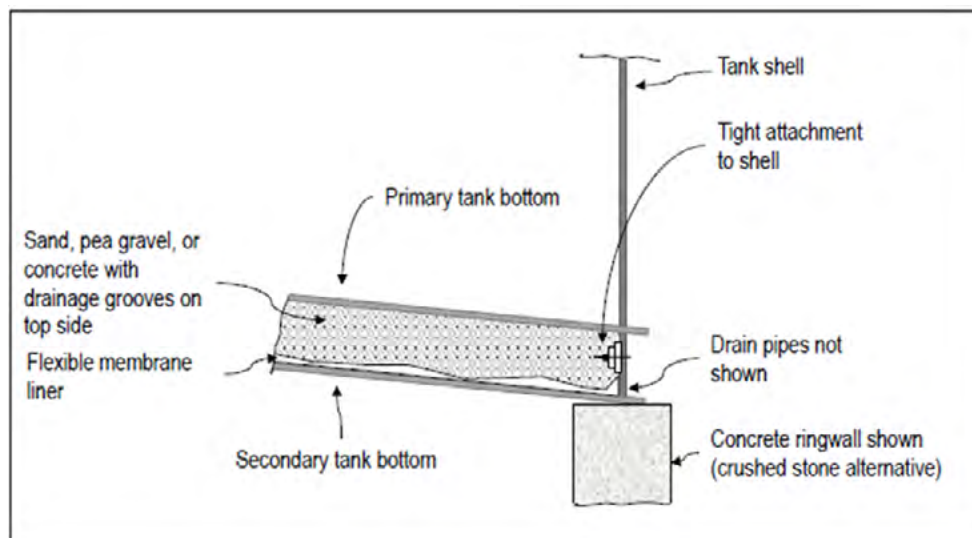


Figure 3: Example of Double Bottom Tank

5.3.5.2 New primary steel bottoms are often installed above the original primary bottoms to provide for leak detection and containment.

5.3.5.3 The new primary steel bottoms are constructed in various configurations based on operational requirements.

5.3.5.4 Secondary steel bottoms may be an alternative to flexible membrane liners installed under a layer of soil.

5.3.5.5 All corrosion control design considerations for primary bottoms including CP and VCI are applicable.

5.3.5.6 Effective sealing between the primary and the secondary bottoms shall be established if VCIs have been selected as a corrosion control system.

5.3.6 Double Bottoms with Steel Members

5.3.6.1 Another configuration for the double steel bottoms is using steel members such as gratings, structural shapes, or wire mesh to separate the bottoms. Secondary bottoms are either placed on grade directly or on a concrete slab as shown below in Figure 4 and Figure 5.

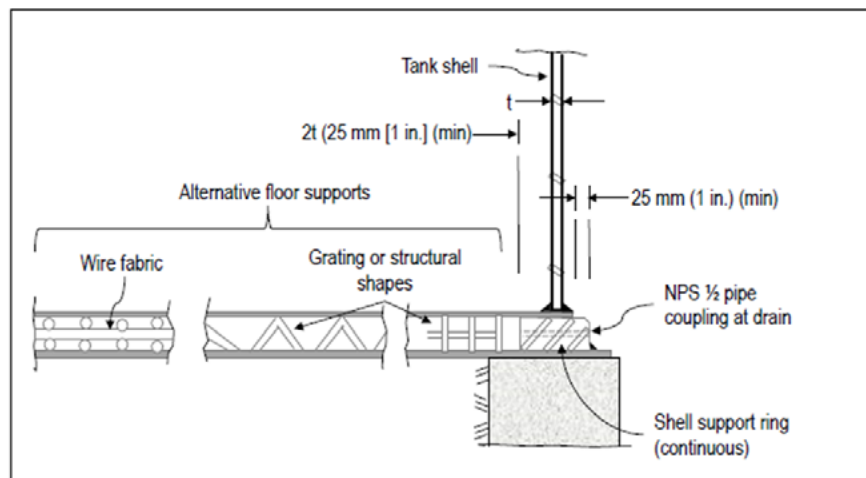


Figure 4: Example of Double Bottoms Using Steel Members to Support the Bottoms Where the Secondary Bottom Sits on Grade

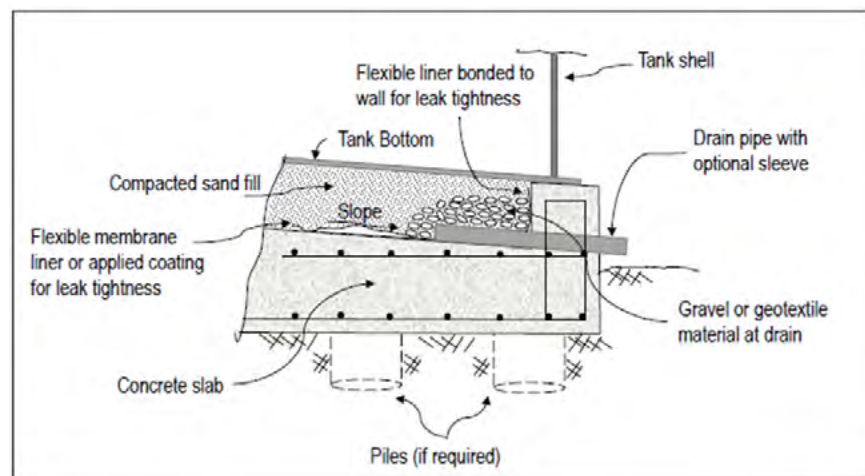


Figure 5: Example of Double Bottoms Using Steel Members to Support the Bottoms Where the Secondary Bottom Sits on Concrete Slab

- 5.3.6.2** Where double steel bottoms are using steel members, sealing of the bottom's perimeter shall be established to prevent the ingress of water and the potential corrosion risk.
- 5.3.6.3** The integrity of leak detection drain systems is critical to minimize the accumulation of water and leaked product above the secondary bottom.
- 5.3.6.4** Coating or painting both bottoms and steel structures may be considered to minimize the potential corrosion risk.
- 5.3.6.5** When the secondary bottom is not sitting on a concrete slab, a separate corrosion control system may be designed for the external side to provide the required protection.

5.3.7 Tanks with Containment Liners

- 5.3.7.1** Containment liners are installed under the tank bottom to allow for detection and containment of leaks while reducing environmental risk in the event of a product leak.
- 5.3.7.2** Containment liners are electrically conductive when made from clay materials. Containment liners made from plastics high-density polyethylene (HDPE) are typically not electrically conductive (di-electric). Di-electric liners do not allow passage of CP current. Hence, anodes must be installed between the liner and tank bottom for the CP system to be effective, as shown below in Figure 6.
- 5.3.7.3** Containment liners trap water or any leaked products under the tank bottom. This may increase the external corrosion rates of the tank bottom.

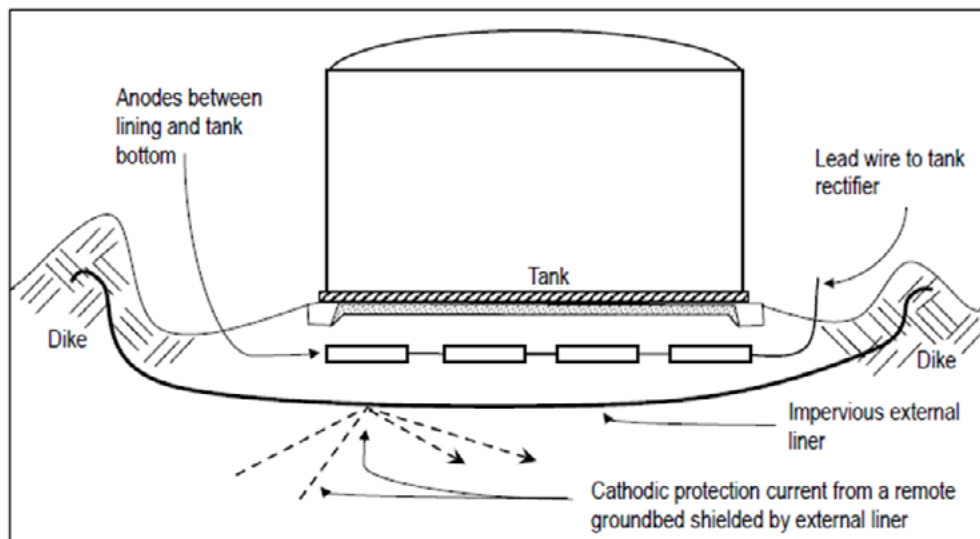


Figure 6: Example of the Containment Liner Under Tank Current Shielding Effect on Cathodic Protection Current

Section 6: Determination of Need for Supplemental Corrosion Control Systems

6.1 Introduction

- 6.1.1 Many factors contribute to a possible need for supplemental AST corrosion control systems. The decision to introduce a supplemental or alternative corrosion control system is case-specific and determined by the unique circumstances governing each situation.
- 6.1.2 In some instances, conventional CP corrosion control may not be absolutely effective, and a viable supplementary method or alternative may become necessary. In such cases, external side bottom corrosion may be controlled using VCIs. VCIs by nature diffuse into the void spaces throughout the free space between sand/soil particles to protect the exposed steel where CP is ineffective.

6.2 Potential Prerequisites for Supplemental Corrosion Control

- 6.2.1 Loss of tank product containment resulting in contamination of the sand pad.
- 6.2.2 Application of poor-quality sand during tank construction or contamination of the sand pad by intrusion of water undertank from the tank dike containment area.
- 6.2.3 Out-of-service inspection (API 653) data indicating a rate of external corrosion that impacts the design life of the tank bottom.
- 6.2.4 Extending out-of-service tank inspection intervals that necessitate action to mitigate failure mechanisms.
- 6.2.5 Changes in data from undertank corrosion monitoring systems indicating increased concerns of tank bottom corrosion.
- 6.2.6 History of corrosion from tank bottom inspection data on “similar service” tanks at the facility.
- 6.2.7 Changes in tank operating conditions including:
 - 6.2.7.1 Increased operating temperature of products contained in a tank.
 - 6.2.7.2 Extended out-of-service periods or prolonged tank idling.
- 6.2.8 Regular extensive fill/empty tank product cycles resulting in consistent reduction of bottom plate contact with the sand pad.
- 6.2.9 Frequent and prolonged de-energizing of CP systems requiring establishment of a detailed and appropriate test scope for scheduled tank outages that explicitly demonstrates the effectiveness of corrosion mitigation method(s).
- 6.2.10 Inability to demonstrate, apply, or retrofit effective CP due to:
 - 6.2.10.1 Di-electric liners or double bottom configurations
 - 6.2.10.2 Inadequate CP due to design limitations
 - 6.2.10.3 CP current distribution restrictions
 - 6.2.10.4 Anode groundbed failure/exhaustion

6.3 Indicators of Reduction in External Corrosion Control

- 6.3.1** Identification of external corrosion in excess of an Operator's acceptable limits should initiate investigation of options to increase the effectiveness of existing corrosion control systems or consideration of supplemental corrosion control measures.
- 6.3.2** Real-time external corrosion data may be obtained by API 653 tank bottom scan inspection reports. These are key indicators of external corrosion control system effectiveness. The reports provide an abundance of information for consideration.
- 6.3.3** Undertank corrosion monitoring system data as described in [Section 5](#) are a significant resource for existing corrosion control effectiveness evaluation between out-of-service inspection intervals. The data is also very useful for measurement of changes in electrolyte (sand pad) corrosiveness.

6.4 Processes to Determine Applicability of Supplemental Corrosion Control Systems

- 6.4.1** Tanks with CP systems that have failed, systems that exhibit insufficient current output, or demonstrate unacceptable tank bottom-to-soil potentials are a concern for reduced corrosion control.
 - 6.4.1.1** If this occurs on double-bottom tanks, or single-bottom tanks with di-electric liners below the bottoms, repair/replacement of the CP systems is not possible without tank bottom removal. In these instances, options for supplemental systems such as VCI that can be installed with the tanks in service may be considered.
 - 6.4.1.2** If installation of a new CP system design, or replacement of an existing system, is possible without tank service disruption or bottom removal requirements, then sound engineering practices should be utilized that consider the effectiveness of the previous CP system.
- 6.4.2** When tank bottom corrosion is indicated per the parameters in [Paragraph 5.3](#) and the existing CP system testing data conforms with AMPP criteria for cathodic protection, then the following may be considered.
 - 6.4.2.1** Thorough evaluation which reliably demonstrates the presumed level of protection provided by the existing CP system(s).
 - 6.4.2.2** Tanks with galvanic CP systems. It is unlikely adjustments can be made to improve CP. Where applicable, a supplemental impressed current CP system may be considered. Consideration of VCI application is also an option.
 - 6.4.2.3** Tanks with impressed current CP systems. Adjustments to increase system output or CP system design changes are a consideration.
 - 6.4.2.4** It is feasible that other factors as listed in [Paragraphs 5.2](#) and [5.3](#) are considerations indicating a need for a supplemental VCI system application on cathodically protected tank bottoms.
- 6.4.3** Evaluation of the undertank electrolyte (sand pad) as described in Section 6 is a governing factor in determining whether supplemental corrosion control techniques are appropriate or even feasible.
 - 6.4.3.1** Composition analysis of the padding in conjunction with the tank foundation's civil design often dictates the options available for managing corrosion beyond CP.
 - 6.4.3.2** Laboratory testing of supplemental systems such as VCI can provide useful effectiveness analysis if the testing is performed with actual electrolyte (sand pad) material samples that have been properly obtained, handled, and stored to preserve all their chemical characteristics.

6.5 Risk-Based Determination of Need for Supplemental Corrosion Systems

- 6.5.1** The decision to invest in additional corrosion control efforts may be determined using a risk-based approach.
- 6.5.2** Utilizing this approach provides a practical method of corrosion management based on the principles of ISO 31000: Risk Management - Principles and Guidelines.
- 6.5.3** A 5-step process involving pre-assessment, screening and risk ranking, detailed examination, remediation and repair, and life-cycle management are the fundamental components that should be considered. Table 2 outlines a risk assessment based on the chemical characteristics of the electrolyte (sand tank pad) that is in contact with the bottom plates.

NOTE: Significant study is underway to develop technically applicable Risk Ranking criteria for AST sand pad electrolyte materials. Future revisions of this standard should contain these criteria.

Table 2
AST Sand Pad Risk Rank Example

	Corrosive	Moderately Corrosive	Mildly Corrosive
Numbering Criteria	High-1	Medium-2	Low-3
pH	<5	5-8	>8
Chloride (ppm)	>100	10-100	<10
Sulfides (ppm)	TBD	TBD	<0.1
Sulfates (ppm)	>200	50-200	<50
Resistivity (ohm-cm)	<5,000	5,000-10,000	>10,000
Bacterial Growth (Colonies/mL)	>10,000	1,000-10,000	<1,000
Cumulative Risk Rank	<8	8-9	>10

Section 7: Technologies to Evaluate and Monitor External Side Corrosion on Tank Bottoms

7.1 Introduction

- 7.1.1** Management of external corrosion on AST bottom plates is complex. Numerous corrosion cells may develop on the bare or partially coated steel plates due to varying tank pad materials combined with an assortment of contaminants that are often introduced into the tank pad during construction. Numerous other factors also contribute to the challenge of mitigating corrosion of bare steel in contact with a variable electrolyte.
- 7.1.2** Electrolyte characteristics substantially affect the type and rate of corrosion on a tank bottom contacting an electrolyte. For example, dissolved salts influence the current carrying capacity of the electrolyte and help determine reaction rates at the anodic and cathodic areas. Moisture content, pH, oxygen concentration, and other factors interact in a complex fashion to influence corrosion. Therefore, it is valuable to evaluate, characterize and monitor the tank pad electrolyte influencing the corrosion of the steel.
- 7.1.3** Intermittent out-of-service tank bottom inspection scans identify and measure external metal loss. This data should be used to characterize, evaluate, and correct any deficiencies in the external corrosion prevention plan utilized for the tank bottom.

7.2 Tank Pad Electrolyte Evaluation and Characterization

7.2.1 To better understand the effective solutions for the prevention of external corrosion on steel tank bottom plates, it is important to properly evaluate and characterize the electrolyte (typically sand) in contact with the steel.

7.2.1.1 Despite quality control efforts dictated by API 651, contaminants and soils are commonly mixed into the sand during handling and are difficult to quantify once bottom construction is completed. The results of the first API 653 tank bottom inspection are valuable for the identification of local corrosive environments that developed due to these contaminants. Corrective actions during the first out-of-service interval may be necessary to mitigate severe corrosion from tank pad contaminants introduced during construction.

7.2.1.2 Electrolyte corrosiveness may change if a leak occurs in a tank bottom or water migrates into the sand pad. Corrosion cells that did not previously exist may be created or the effectiveness of corrosion control systems may be adversely affected. A leak may also move the pad material and eliminate the contact of the tank bottom with the tank pad in some areas.

7.2.2 Characterization of the tank pad electrolyte corrosiveness can be completed through proper processes for sampling the tank pad sand below the tank bottom and above the native soil.

7.2.2.1 Due to a variety of reasons, it is typically not sufficient to sample and test the sand under one tank at a multiple tank terminal and assume other tank pad sands have the same characteristics. Evaluation of the sand pad electrolyte under each tank should be completed.

7.2.2.2 If an API 653 bottom inspection report has been completed, the results can be leveraged to target meaningful undertank locations for sand sampling. The locations should consist of those where external corrosion was identified during the inspection, plus a control location without external corrosion.

7.2.2.3 The number of sand samples required to adequately characterize the electrolyte varies according to numerous factors. These factors include tank diameter, bottom scan data, leak history, owner preference, budgets, etc. A minimum of one sand sample per quadrant of the tank bottom is recommended. Additional sample locations for larger tanks (i.e., greater than 150 feet) should be obtained.

7.2.2.4 Technology is available to safely create a horizontal hole below and close to the tank bottom for sample collection. The safe distance below the tank bottom and the horizontal distance towards the tank center vary according to the equipment utilized, undertank conditions, and tank owner allowances. Caution should be used when creating holes under tanks to ensure that the tank bottom is not damaged and the tank foundation or pad is not undermined.

7.2.2.5 Sand sample extraction should be conducted in a way that ensures clean undisturbed samples are obtained. The extracted samples should be properly handled and packaged then shipped to the designated laboratory for analysis.

7.2.3 Sand sample laboratory testing should be performed by a testing laboratory with qualified personnel that utilize the correct testing equipment and adhere to industry standards for the applicable types of analysis.

7.2.3.1 Characterization of field sand sample properties shall include, but are not limited to measurement of sand resistivity, pH, sulfate, sulfide, chloride concentrations, and bacterial activity levels.

7.2.3.2 Microbiologically Influenced Corrosion (MIC) may contribute significantly to severe external corrosion when the electrolyte environment supports this activity. Highly controlled laboratory experiments are utilized to determine the growth of aerobic bacteria and anaerobic bacteria within the tank pad electrolyte that would cause MIC on the tank bottom.

7.2.4 Laboratory evaluation of corrosion prevention technologies using test samples of the tank sand may also be utilized if warranted. This is especially relevant if the electrolyte analysis and coupon testing indicate concerns for MIC. It may be necessary to mitigate the MIC with corrosion biocide/inhibitor chemistry. Therefore, laboratory testing of coupons in the associated bacterial environments is very useful for selecting the correct corrosion prevention program.

7.3 Long-term Corrosion Rate Monitoring

7.3.1 A variety of corrosion rate monitoring technologies are available for installation within the sand electrolyte under a tank bottom and are discussed in [Paragraphs 6.4](#) through 6.6. The data compiled from corrosion rate monitoring systems, in conjunction with API 653 bottom inspection data, are important long-term tank bottom corrosion management indicators.

7.3.2 The data obtained from corrosion rate monitoring systems are used to:

7.3.2.1 Evaluate the effectiveness of active corrosion prevention systems. This information may be used to determine if adjustments or changes to the prevention systems are necessary due to a change in the undertank electrolyte, or due to degradation/failure of the systems.

7.3.2.2 Corrosion rate monitoring systems can also be used for tanks without active corrosion prevention systems. Corrosion rate data is useful for prioritizing tanks that need retrofit corrosion prevention systems and assisting with the determination of out-of-service inspection.

7.3.3 Considerations for the location of corrosion monitoring equipment should include the following:

7.3.3.1 Evaluation of each undertank 90-degree quadrant at a minimum. Larger tank diameters (i.e., greater than 150 ft in diameter) warrant additional monitoring locations, but this is ultimately up to the tank operator.

7.3.3.2 Integration with tank bottom inspection data to be sure areas of concern are monitored.

7.3.3.3 Positioning of the monitoring equipment strategically for evaluation of the corrosion prevention system's effectiveness

7.3.4 General guidelines for the installation of corrosion rate monitoring equipment include the following:

7.3.4.1 Corrosion monitoring equipment shall be installed within the sand tank pad electrolyte upon which the tank bottom is constructed and not be installed within the soils below the tank pad.

7.3.4.2 Corrosion monitoring equipment should be incorporated into assemblies designed for straightforward insertion and extraction. Provisions shall be included that ensure the capability of inserting the corrosion monitoring sensing elements into the tank pad beyond the end of the access pipe.

7.3.4.3 Non-metallic piping, properly sized for the monitoring equipment, shall be installed as close to the tank bottom as safely practical. This access piping provides capabilities for effective insertion and extraction of the monitoring equipment.

- 7.3.5** Corrosion rate monitoring systems provide data used to measure and track the corrosion rates and trends of steel embedded in the sand pad electrolyte close to the tank bottom. These systems are not measuring the actual external corrosion rate on the tank bottom surface.

7.4 Corrosion Coupons

- 7.4.1** Corrosion coupons installed under the tank can be used to assist in tank pad electrolyte evaluations. If access pipes are installed during the sand sampling procedure ([Paragraph 6.2.2](#)), they may be utilized for insertion and removal of coupon assemblies.
- 7.4.2** When feasible, coupons that are of the same steel material as the tank bottom should be utilized. Coupons are typically rectangular shaped, and the surfaces are usually polished clean. Each coupon shall be accurately weighed and labeled prior to installation.
- 7.4.3** If CP is active on the tank, a lead wire should be connected onto the coupon assembly, then connected to the tank. This eliminates stray current corrosion of the coupon and enables the coupon to be used for instant-off CP readings if desired.
- 7.4.4** Installing corrosion coupons at the same locations where sand samples were extracted enables the coupon corrosion rates to be compared with the sand analysis data.
- 7.4.5** During installation, the orientation of the coupon surfaces should be controlled so that a pre-determined surface of the coupon is horizontal and facing downward.
- 7.4.6** After the coupons have been in place for some time, typically 4-6 months, they may be extracted and analyzed in a laboratory to establish the baseline corrosion rate and other characteristics of the electrolyte in each coupon location.
- 7.4.6.1** A report detailing the corrosion rate prediction data of the sand analysis compared to the results of the corrosion coupon testing provides very valuable guidance. This guidance can be used for corrosion prevention system engineering, maintenance, and operation, as well as for input in the decisions on out-of-service tank inspection time intervals.
- 7.4.6.2** Corrosion coupons are used to calculate the total metal loss during the exposure period. A single coupon cannot be used to determine whether the rate of metal loss was uniform or varying during the exposure period.
- 7.4.6.2.1** Information on the change in corrosion rate can be obtained by installing several corrosion coupons at one time, then removing and evaluating a coupon at specific short-term intervals.
- 7.4.6.3** In addition to mass loss, important factors to consider in the analysis and interpretation of corrosion coupon data include location, exposure time, measured pit depth, surface profile (blistering, erosion), corrosion product and/or scale composition, corrosion mechanism (pitting or general), and operating factors. (NACE SP0775).
- 7.4.6.4** Once extracted, the coupons should be handled and processed according to industry standards, coupled with the specific data pertinent to the undertank electrolyte as identified in [Paragraph 6.2](#).
- 7.4.6.5** Benefits of corrosion coupons
- 7.4.6.5.1** The principle of the technique is easily understood
- 7.4.6.5.2** The corrosion loss coupon itself is generally low in cost

7.4.6.6 Limitations of corrosion coupons

- 7.4.6.6.1** The technique is used to determine the average rate of metal loss (uniform corrosion) over the period of exposure. Pitting rates (penetration rates) can be substantially higher than uniform corrosion rates. Pitting rate measurements are made separately with optical microscopes or laser profilometers.
- 7.4.6.6.2** Short exposure periods normally yield unrepresentative average rates of metal loss. This is often the result of higher metal loss during initial acclimation to the under-tank environment, which is not typical of the rate after acclimation.
- 7.4.6.6.3** Determination of the timing or magnitude of corrosion control equipment upsets within the exposure period is not possible.
- 7.4.6.6.4** Corrosion rates can only be calculated after corrosion coupon removal from the system. Used coupons should not be reinserted.
- 7.4.6.6.5** The procedures for corrosion coupon cleaning and analysis are labor intensive, with the consequent additional cost and time required for analysis.
- 7.4.6.6.6** Calculated corrosion rates can be significantly underestimated if the mass loss is great and the coupon is relatively small where the initial non-corroded coupon area is changed significantly by the high corrosion through the period of exposure

7.5 Electrical Resistance (ER) Probes

- 7.5.1** The electrical resistance of a measurement element increases as its conductive cross-sectional area decreases as a result of corrosion, erosion, or a combination of both. The change in the resistance value measured is then used to determine a corrosion rate. The probe life is a function of the measurement element thickness.
 - 7.5.1.1** To avoid inaccuracies caused by temperature changes, an electrical resistance ratio is calculated between a measurement element exposed to the test environment and a reference element protected from the environment.
 - 7.5.1.2** Sensitive measurement electronics are needed for ER probes due to the very small electrical resistance of the measurement element.
 - 7.5.1.3** ER probe corrosion rates rely on the assumption that the cross-sectional area of the measurement element decreases uniformly during the measurement time period.
- 7.5.2** Benefits of ER Probes
 - 7.5.2.1** ER probe corrosion rates can be continuously collected and reported through remote monitoring units (RMUs).
 - 7.5.2.2** This technique can be used in virtually any environment.
 - 7.5.2.3** Process upsets and other corrosive conditions can be detected quickly to enable immediate remedial action. High-resolution ER probe systems provide a faster response.
 - 7.5.2.4** Measurements are made without the need to withdraw probes from the tank pad.

7.5.2.5 This technique is useful for monitoring of a tank pad corrosion inhibition program.

7.5.3 Limitations of ER Probes

7.5.3.1 Corrosion rate results are representative of metal loss by general corrosion. ER probes are less sensitive to the effects of localized attack.

7.5.3.2 The response time of ER probes is a direct function of the measurement element thickness. The thicker the element, the more time is required to establish the corrosion rate (hours to days). Thinner ER probes can have a shorter response time for determining corrosion rates but reach the end of their useful life quicker.

7.5.3.3 In some situations, partially conductive deposits such as iron sulfide reduce apparent corrosion rates or show metal gain.

7.5.3.4 Although the ER probe measurements are corrected for temperature change by having a reference element, there can still be small changes in the measurements with large temperature swings.

7.5.3.5 The ER probe itself has a finite service life.

7.6 **Ultrasonic Transducer (UT) Probes**

7.6.1 These undertank corrosion rate probes incorporate ultrasonic transducer (UT) technology.

7.6.2 At the time of this writing, the use of this technology under tank bottoms is evolving and has not been the subject of AMPP technical evaluation and opinion. However, it has significant promise and unique capabilities for corrosion rate monitoring of the tank pad electrolyte.

7.6.3 The corrosion probes consist of a coupon with a pair of ultrasonic transducers affixed under the coupon. The coupon is typically the same type of steel as the tank bottom and can be supplied with mill-scale on the surface or with a polished surface. This assembly is embedded within a non-metallic housing.

7.6.4 The technology provides the ability for on-demand measurement of coupon thickness at each transducer. It also provides the ability to measure the mass of the coupon between transducers. This mass measurement is compared over time for the identification of metal loss.

7.6.5 Benefits of UT Probes

7.6.5.1 UT probes directly measure the corrosion of a metal coupon, unlike ER probes, which rely on the relationship between resistance and surface area.

7.6.5.2 Coupons can be extracted and corrosion features can be visually examined.

7.6.5.3 Corrosion rate data can be continuously collected and recorded with RMUs.

Section 8: Vapor Corrosion Inhibitor Technologies and Application for Tank Bottoms

8.1 Explanation of the Chemistry

External corrosion of aboveground storage tank bottoms is an ever-present problem. VCIs provide effective corrosion prevention to the external surfaces of steel storage tank bottoms when applied and monitored correctly. VCIs may be used in addition to other corrosion prevention processes or applied as a stand-alone corrosion prevention system. An important distinction of VCI technology is that when applied within a tank pad electrolyte, diffusion of molecules continuously occurs through the electrolyte to all the tank bottom surface regardless of whether the bottom plate is in contact with the electrolyte or is not in contact. Vapor emission from the VCI chemistry continues until the VCI totally dissipates over a long period of time.

- 8.1.1** VCIs are a class of corrosion inhibitors that act primarily by modification of the chemical environment at the steel surface. Carbon steel is the most common metal used in the construction of storage tanks and therefore, the chemistry described is for carbon steel. Different VCI formulations are available when metals other than carbon steel are considered.
- 8.1.2** VCIs continually release vapors that disseminate until equilibrium determined by the partial vapor pressure is reached. The VCI should be contained in a closed environment to limit its exhaustion timeline. Once released, molecules interact with metallic surfaces to protect from further corrosion through a multitude of different mechanisms. These can include blocking - chemical adsorption, chemical passivation, and pH modification.
- 8.1.3** VCIs are compounds that vaporize or sublime and condense on the tank bottom surface, forming a molecular layer that mitigates the naturally occurring active corrosion mechanisms.
- 8.1.4** VCIs are supplied in different formulations including powder, liquid, films, paper, foams, capsules, tubes, and rods designed to release vapor molecules over time. An advantage of VCIs compared with other corrosion control methods stems from their vapor transport mechanism. This enables migration of VCI molecules to a metallic surface without direct surface contact by the chemistry.¹
- 8.1.5** Vapor pressure of a chemical compound largely depends upon the structure of the crystal lattice and the character of the atomic bonds in the molecule. High vapor pressure compounds reach the protective vapor concentration rapidly, but in the case of enclosures that are not airtight, the consumption of inhibitor is quick and resulting protective periods are short. Alternatively, low vapor pressure VCIs require more time to achieve a protective vapor concentration and therefore can last longer, providing more durable protection.
- 8.1.6** Once they reach the metal, VCI molecules adsorb onto the surface by a physical (electrostatic) and chemical process. This process is governed by the residual charge of the metal and the chemical structure of the inhibitor. VCIs are further classified as cathodic, anodic, or mixed, depending on which reaction they suppress.²
- 8.1.7** The use of VCIs for tank bottoms shall be engineered to deliver the desired service life, taking into consideration multiple design parameters. Evaluation of VCI chemistries on CP system components and the impact on CP parameters has been researched³⁻⁷ and should be considered when applicable.
- 8.1.8** VCI products are easily replaced/replenished when necessary.

8.2 Engineering and Design Requirements

- 8.2.1** VCI systems are designed and installed to mitigate corrosion of a tank bottom's external surfaces. A variety of tank bottom and foundation configurations currently exist. Therefore, VCI system designs are tank-specific. This section provides general recommendations for the design and in-

stallation of a VCI system. Before implementation of any VCI system, a VCI Specialist should be consulted for the best methods of effective corrosion control for each tank design.

8.2.2 Contamination of the interstitial space in which VCI is applied is an important consideration. The intrusion of fresh air and water shall be controlled where possible.

8.2.3 VCI manufacturers have products typically recommended for AST systems. However, a variety of other VCI products exist. If the results of a tank pad electrolyte evaluation, as discussed in Paragraph 6.2, identify unusual or very aggressive corrosion characteristics, there may be a need to perform testing and identify which VCI product is most effective.

8.2.3.1 Samples of the electrolyte may be utilized in a laboratory experiment to evaluate VCI effectiveness and ensure the correct VCI chemistry is matched with the electrolyte.

8.2.3.2 Undertank field tests may also be performed to ensure a particular VCI chemistry is effective within a unique electrolyte.

8.2.4 VCI systems may be installed on a tank while in-service, out-of-service, or during new tank construction. The major objectives of VCI system design for tank bottoms are to:

8.2.4.1 Deliver and distribute sufficient corrosion inhibitor chemistry for the external side of the tank bottom surface to ensure that corrosion control is achieved.

8.2.4.2 Provide a design life for the VCI system and other equipment commensurate with the design life or API 653 inspection intervals of the tank.

8.2.4.3 Provide a means to monitor VCI system performance within the tank pad electrolyte to determine that the corrosion mitigation criterion is achieved.

8.2.4.4 Provide a plan for periodic replenishment of the corrosion inhibitors.

8.2.4.5 Evaluate any environmental concerns per geographical location and tank operator standards.

8.2.5 A VCI Specialist should design the VCI systems and the process to apply the VCI below the tank bottom.

8.2.6 The VCI chemical recommended for an AST installation shall have documented effectiveness in AST applications. The chemical shall be a multi-phase corrosion inhibitor capable of producing continuous molecular distribution throughout the interstitial space beneath the tank bottom, regardless of the moisture concentration within the interstitial space.

8.2.7 The VCI Specialist should specify the dosage of VCI chemistry to be applied in accordance with the VCI manufacturer's recommendations.

8.3 VCI Safety and Environmental Precautions

8.3.1 It is important to consult the Manufacturer's Product and Safety Data Sheets (SDS) of specific VCI products under consideration for usage during the engineering, design, and application processes. The SDS provides hazard identification, information on ingredients, first aid, firefighting, and accidental release measures. Additional handling and storage, personal protective equipment (PPE) recommendations, physical and chemical properties, stability, toxicological, and ecological information is provided, along with disposal considerations, transport, and regulatory information.

8.3.2 Many VCI products are biodegradable and do not contain hazardous chemical components. However, environmental regulations should be considered as appropriate for each specific jurisdiction and for each specific VCI application.

- 8.3.3** A Job Hazard Analysis and Site-Specific Safety Plan shall be developed and followed for all VCI application and maintenance projects.
- 8.3.4** When using the powdered VCI products, accumulation of dust may need to be considered and controlled to eliminate any potential combustible environments. Consult the SDS of the specific VCI product being used.
- 8.3.5** If VCI powder is applied near welding operations, the powder shall not be applied in or near the weld zone and shall be prevented from becoming present in the weld zone. The powder may affect the quality of the weld, as would other foreign materials.

8.4 Methods of Applying VCI

- 8.4.1** VCI may be installed below single bottom tanks into the space between a release prevention barrier and the bottom plates; or within the interstitial space between bottoms on a double bottom tank using either a liquid or dry application. The total quantity of VCI chemical that is applied into the interstitial space and the application design should be as specified by a VCI Specialist. The VCI quantity shall be calculated based on the tank dimensions and the dosages recommended by the VCI manufacturer.
- 8.4.2** Processes for applying VCI vary according to the following factors:
 - 8.4.2.1** During new tank bottom construction
 - 8.4.2.2** Tank is in-service or out of service
 - 8.4.2.3** Operating temperature of products stored in the tank
 - 8.4.2.3** Tank bottom and foundation configuration
 - 8.4.2.4** Type of tank pad and its construction design
- 8.4.3** Single Bottom Tanks with Sand Tank Pads.
 - 8.4.3.1** Single bottom tanks constructed on a concrete ring wall with sand fill supporting the bottom plates are good candidates for VCI systems. Multiple designs may be implemented for effective corrosion control using VCIs. See [Figure 7](#).
 - 8.4.3.2** Single bottom tanks with shells supported by compacted gravel or soil may also be candidates for VCI systems. The elevation of the tank bottom and underlying tank pad need to be considered in relation to tank dike surface elevation as well as tank dike drainage after rain events.
 - 8.4.3.3** Existence of a release prevention barrier (RPB) is beneficial for containment of the VCI chemistry. If an RPB was not installed below the tank bottom, additional factors need to be considered prior to VCI system design. These include the sand pad depth, potential for water table intrusion at the sand pad elevation, and type of soil beneath the sand pad.
 - 8.4.3.4** In-service tanks: VCIs in powder or liquid form may be applied and distributed throughout the undertank external environment as well as the annular chime ring area.
 - 8.4.3.4.1** The VCI chemistry is typically delivered through a perforated injection piping network properly designed by a VCI Specialist. The piping network shall be designed to produce uniform distribution of the VCI chemistry throughout the tank pad.

8.4.3.4.2 The injection pipe shall be installed with technology that enables the safe placement of the pipe within the tank pad sand at a reasonable distance from the tank bottom.

NOTE: Due to safety concerns, rotational drilling equipment is not recommended for this application.

8.4.3.4.3 Existing perforated piping already in place for leak detection or CP purposes may be utilized if it is deemed to be suitable for this purpose.

8.4.3.4.4 Once the injection piping network is in place, the specified volume of VCI products shall be applied through the pipe network.

8.4.3.5 Out-of-service tanks: Tanks that are out of service, cleaned, and safe for manned entry offer an option in addition to the methodology described in Paragraph 8.4.3.4.

8.4.3.5.1 VCI chemistry, typically in the liquid form, is applied through a temporary injection port network installed in the bottom plates. This network should be properly designed by a VCI Specialist. The injection port network shall be designed to produce uniform distribution of the VCI chemistry throughout the tank pad.

8.4.3.5.2 Once the injection port network is in place, the specified volume of VCI products shall be applied through the network.

8.4.3.5.3 After VCI application, the temporary ports are removed and small patch plates shall be welded over the holes in the bottom plates.

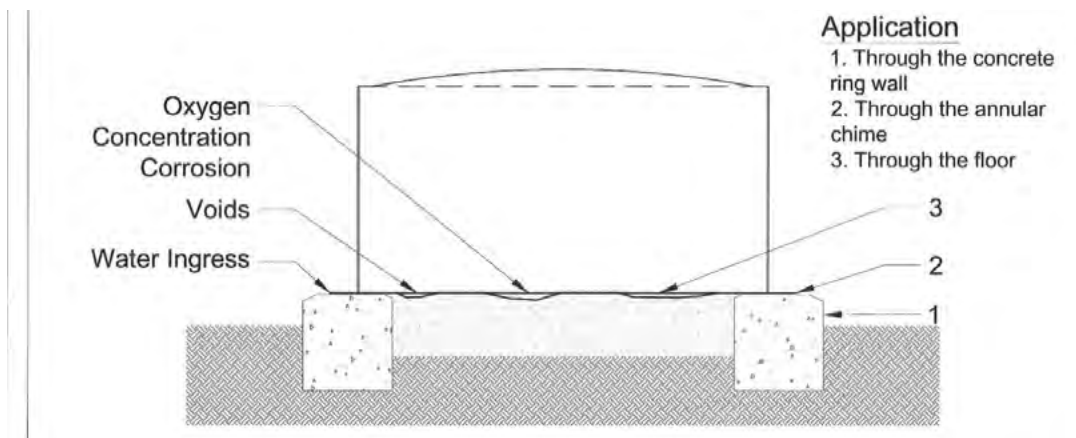


Figure 7: Diagram of Common VCI Application for Aboveground Storage Tanks on Concrete Ring Wall and a Sand Tank Pad

8.4.4 Single Bottom Tanks with Concrete/Asphalt/Limestone Tank Pads

8.4.4.1 These types of tank pads severely limit the effectiveness of CP as a corrosion protection option. Water and contaminants can ingress through the annular chime area. This is dependent upon the slope of the tank pad and the seal of the tank chime area. VCIs may be introduced between the tank pad and the steel surface to mitigate corrosion. See [Figure 8](#).

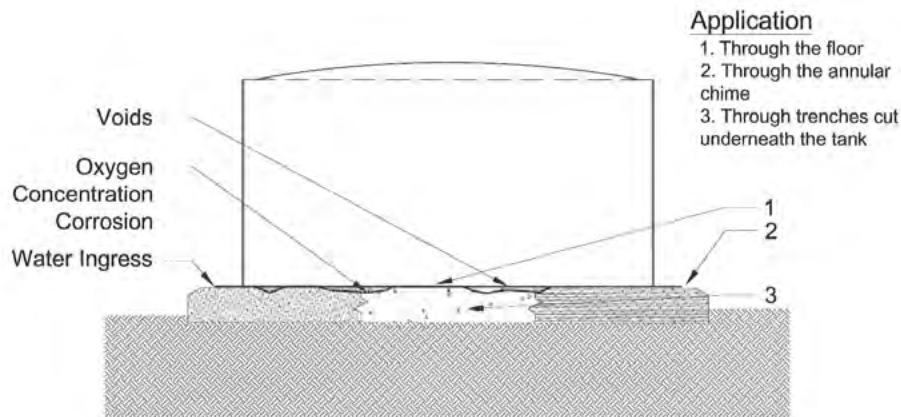


Figure 8: Diagram of Common VCI Application for Aboveground Storage Tanks on Concrete/Asphalt/Limestone Tank Pads

8.4.4.2 Various ways to introduce VCIs into the tank bottom environment are: chime area application, through the tank bottom, and through slots/trenches pre-formed into the concrete.

8.4.4.3 In-service tanks: VCI application methods are very limited for these tanks while in-service. There are options to incorporate slots or other VCI application accesses into these tank pads during the construction process if desired. VCI is then able to be applied at any time while the tank is in-service.

8.4.4.4 Out-of-service tanks: Tanks that are out of service, cleaned, and safe for manned entry offer an option in addition to the methodology described in Paragraph 8.4.4.3.

8.4.4.4.1 VCI chemistry, preferably in the liquid form, is applied through a temporary injection port network installed through the bottom plates. This network should be properly designed by a VCI Specialist. The port network shall be designed to produce uniform distribution of the VCI chemistry throughout the tank pad.

8.4.4.4.2 Once the injection port network is in place, the specified volume of VCI products shall be applied through the network.

8.4.4.4.3 After VCI application, the temporary ports shall be removed and small patch plates shall be welded over the holes in the floor plates.

8.4.5 Double-Bottom Tanks

8.4.5.1 The floors of double-bottom tanks are generally separated by sand or concrete. Metallic and non-metallic mesh or grid-type materials have also been installed between the bottoms of some tanks. VCIs are well-suited for all these tank configurations, especially when the interstitial space is well-sealed. Multiple designs may be implemented for effective corrosion control using VCIs. See [Figure 9](#).

8.4.5.2 In comparison to CP technology for these types of tanks, VCI systems offer significant differences for consideration.

8.4.5.2.1 Due to the typically narrow width of space between bottoms, distribution of CP anode current to all of the bottom plate surface may be a concern. The narrow space is ideal for VCI molecular distribution to all the bottom plate surface.

8.4.5.2.2 Once the anodes are consumed or undertank anode cables fail, CP systems are not replaceable for double-bottom tanks without removal of the upper bottom. Once the VCI is consumed, it can be readily replenished.

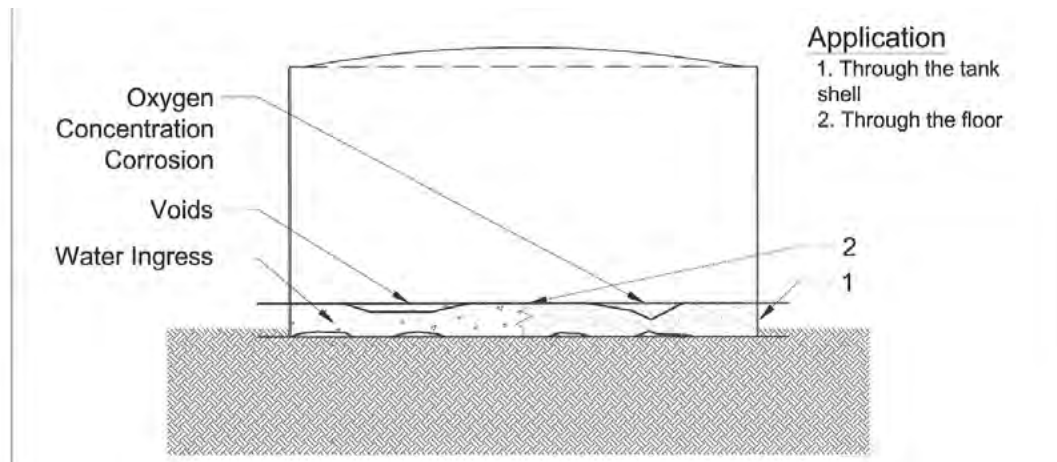


Figure 9: Diagram of Common VCI Application for Aboveground Storage Tanks on Double Bottom Foundation with Sand/Concrete Fill

8.4.5.3 Double-Bottom Tanks with Sand Between the Bottoms: These tanks are appropriate candidates for VCI technology.

8.4.5.3.1 In-service tanks: VCIs in powder or liquid form may be applied and distributed throughout the interstitial space between the bottoms.

8.4.5.3.1.1 The VCI chemistry is delivered through a perforated injection piping network properly designed by a VCI Specialist. The piping network shall be designed to produce uniform distribution of the VCI chemistry throughout the space.

8.4.5.3.1.2 The injection pipe shall be installed with technology that enables the safe placement of the pipe within the tank pad sand at a reasonable distance from the tank bottom.

NOTE: Due to safety concerns, rotational drilling equipment is not recommended for this application.

8.4.5.3.1.3 Existing perforated piping already in place for leak detection or CP purposes may be utilized if it is deemed to be suitable for this purpose.

8.4.5.3.1.4 Once the injection piping network is in place, the specified volume of VCI products shall be applied through the pipe network.

8.4.5.3.2 Out-of-service tanks: Tanks that are out of service, cleaned, and safe for manned entry offer an option in addition to the methodology described in Paragraph 8.4.5.3.1.

8.4.5.3.2.1 VCI chemistry, typically in the liquid form, is applied through a temporary injection port network installed on the bottom plates. This network should be properly designed by a VCI Specialist. The port network shall be designed to produce uniform distribution of the VCI chemistry throughout the tank pad.

8.4.5.3.2.2 Once the injection port network is in place, the specified volume of VCI products should be applied through the network.

8.4.5.3.2.3 After VCI application, the temporary ports shall be removed and small patch plates shall be welded over the holes in the floor plates.

8.4.5.4 Double-Bottom Tanks with Concrete between the Bottoms: VCIs may be utilized for these tanks.

8.4.5.4.1 In-service tanks: VCI application methods are limited for these tanks while in-service. There are options to incorporate slots or other VCI application accesses into these tank pads during the construction process if desired. VCI is then able to be applied at any time while the tank is in-service.

8.4.5.4.2 Out-of-Service Tanks: VCI chemistry, typically in the liquid form, is applied through a temporary injection port network installed on the bottom plates. This network shall be properly designed by a VCI Specialist. The port network shall be designed to produce uniform distribution of the VCI chemistry throughout the tank pad.

8.4.5.4.3 Once the injection port network is in place, the specified volume of VCI products shall be applied through the network.

8.4.5.4.4 After VCI application, the temporary ports shall be removed and small patch plates shall be welded over the holes in the bottom plates.

8.4.5.5 Double Bottom Tanks with Mesh or Grid-Type Materials Between the Bottoms: VCI may be applied within the interstitial space of these tanks. See [Paragraph 8.4.5.3](#) for similar VCI application guidance.

8.5 Methods of Evaluating and Monitoring the Effectiveness of VCI Systems

8.5.1 Technology does not presently exist to perform in-situ measurements of active VCI chemistry concentrations within a tank pad where a VCI system has been applied. Presently available technology is limited to the use of ammonia sensors for an indirect assessment of VCI concentrations. However, this technology and others are under development to produce in-situ measurement of VCI chemistry concentrations and may eventually become viable.

8.5.2 Present practices utilized to evaluate and monitor the tank pad electrolyte (see Section 7), in combination with API 653 tank bottom inspections, provide functional options for monitoring of VCI effectiveness.

8.5.3 Corrosion Rate Monitoring of the Tank Pad Electrolyte: Mass-loss type corrosion rate monitoring devices producing mils per year (mpy) metal loss data as described in [Paragraph 7.3](#) are the preferred tools for evaluation of VCI effectiveness between tank bottom inspection intervals. These technologies are employed to measure the corrosiveness of the tank pad electrolyte within close proximity of the tank bottom. Corrosion rate data indicating a trend of increasing electrolyte corrosivity may indicate a need to replenish VCI as specified in Paragraph 8.6.

8.5.3.1 The required number and location of corrosion rate monitoring devices are dependent upon the following factors.

8.5.3.1.1 Tank diameter. A minimum of four corrosion monitoring devices should be located closely below the tank bottom at each 90-degree quadrant. The distance under the tank of the corrosion monitoring devices, and the installation of additional monitoring devices for larger tanks, shall be determined per VCI Specialist and tank operator specifications.

8.5.3.1.2 API 653 tank bottom inspection data. The number and location of corrosion rate monitoring devices may also be impacted by the results from API 653 tank bottom inspections. There is value in monitoring the electrolyte close to bottom plates that are experiencing aggressive corrosion to ensure the VCI is mitigating the electrolyte corrosiveness.

8.5.3.1.3 Strategic positioning of corrosion rate monitoring devices. This includes locations that are midway between VCI injection points. These midway points could be considered the “least protected” locations. Therefore, if corrosivity is acceptable in these midway locations, it is reasonable to assume the corrosivity is equal to, or less, at locations closer to the VCI injection points.

8.5.3.2 Intervals for obtaining monitoring device corrosion rate data. The monitoring devices shall be examined a minimum of twice each calendar year with intervals not exceeding 7.5 months. The corrosion rate data shall be recorded and compared with past data to produce an evaluation of changes in the corrosivity of the tank pad electrolyte.

8.6 Criteria and Methods for Replenishing VCI

8.6.1 Criteria for VCI Replenishment: As discussed in Paragraph 8.5, the technology does not exist at this time to evaluate the real-time volume of active VCI chemistry contained within the tank pad electrolyte. Present practices utilized to evaluate and monitor the tank pad electrolyte, as well as API 653 tank bottom inspection data analysis, are proven functional options for evaluating VCI effectiveness.

8.6.1.1 The following criterion was determined empirically by research.⁷ It is not intended that persons responsible for AST corrosion control and maintenance be limited to this criterion for all conditions and at all locations. The research indicated that based upon the tank operator’s guidance, important corrosion indication benchmarks for maintenance identified and recorded during API 653 tank bottom inspections generally equaled 5 mpy rates of corrosion. Corrosion indications with lower rates are typically not recorded unless desired due to an increase in the tank inspection interval.

8.6.1.2 Corrosion monitoring device criteria for VCI replenishment. If a 5 mpy, or greater, corrosion rate is measured with a monitoring device over two consecutive measurement periods, the VCI shall be replenished. At a minimum, the VCI shall be replenished within the specific tank quadrant area where the corrosion monitoring device is located.

- 8.6.1.3 Tank bottom inspection data. If tank bottom inspection results identify corrosion indications of 5 mpy, or greater, the VCI shall be replenished. At a minimum, the VCI shall be replenished within the specific tank quadrant area where the corrosion indication is located.
- 8.6.1.4 Scheduled replenishment. If, during an initial VCI installation process, there was a determination that the VCI should be replenished after a specified length of time, the tank operator shall ensure the replenishment is completed per this guideline.
- 8.6.2 Methods for Replenishing VCI: Replenishment of VCI is accomplished with the same alternatives as described in [Paragraph 8.3](#) for the specific types of tank construction and service. Factors that assist with determining the preferred replenishment design include:
 - 8.6.2.1 The existence of VCI injection piping or ports that were included with the original VCI application.
 - 8.6.2.2 Total area requiring VCI replenishment. The criterion for replenishment listed in Paragraph 8.6.1 includes requirements for VCI application in specific tank quadrants. Therefore, areas targeted for VCI replenishment shall be addressed at a minimum.

Section 9: Application of Cathodic Protection to Control External Corrosion of Carbon Steel On-Grade Storage Tank Bottoms

- 9.1 For further information on this subject, see NACE SP0193.

Section 10: Protective Coatings for the External Surface of Tank Bottoms

- 10.1 Coatings in Section 10 do not include the internal side of tank bottoms. Coatings of the external sides are optional and must be used in conjunction with other corrosion prevention systems.
 - 10.1.1 CP technology used in conjunction with protective coatings is well-known throughout the aboveground storage tank industry to be an effective method for protecting steel tanks from corrosion. The use of protective coatings may significantly reduce the current design requirements of CP systems. In cases where the application or operation of CP systems may not be possible or practical, undamaged, properly applied protective coatings offer corrosion protection.
 - 10.1.2 VCI may also be used in conjunction with protective coatings. A VCI system designed for the entire tank bottom can protect any bare steel surface areas caused during welding of plates or other coating-damaged areas.
- 10.2 Coating Material Qualification & Selection
 - 10.2.1 This paragraph presents guidelines for establishing minimum requirements for material selection, surface preparation, and proper application, and to ensure long-term coating performance of liquid-epoxy coatings applied to external tank bottoms.
 - 10.2.2 The coating system should be qualified by the owner prior to coating application to verify that the coating is acceptable for the tank pad material upon which the coated plates are installed. This testing should be conducted on each applicable coating system to meet the acceptance criteria. It is the responsibility of the owner to perform or establish the criteria for these tests. Once qualification is established, further qualification testing is not required unless there is a change in coating material, formulation, or location of manufacture. There may be a variety of other tests that the owner may wish to perform to verify the coating meets requirements.

- 10.2.2.1** Cathodic Disbondment Resistance – 28 days, ASTM G95, less than 10 mm
- 10.2.2.2** Impact Resistance – ASTM G14 – greater than 20 in-lbf (2.26 Nm), no cracking or holidays
- 10.2.2.3** Adhesion – ASTM D4541, greater than 10 MPa or 1,450 psi
- 10.2.2.4** Flexibility – TM0304 Flexibility Test, 1.0% elongation or higher

10.3 Surface Preparation

- 10.3.1** The exterior metal surface shall be abrasive blast cleaned to a minimum of a near-white metal finish (NACE No. 2/SSPC-SP 10) or better with an angular surface profile of 2 to 4 mils (0.051 mm to 0.102 mm). A different surface finish should only be allowed when the procedure has been prequalified by the manufacturer and approved by the owner.

10.4 Coating Application

- 10.4.1** Surfaces to be coated shall be clean, dust-free, and dry, and shall meet all surface preparation requirements at the time of coating application.
- 10.4.2** Steel plates shall have a minimum cut-back of 4 in on all four sides to facilitate welding. Steel and coating temperatures during application shall be in accordance with the coating supplier's recommendations.
- 10.4.4** The minimum coating thickness shall be 16 to 25 mils (0.406 mm to 0.635 mm) dry film thickness (DFT) in one coat. If there is concern about curing or other problems, the maximum coating thickness may also be specified by the owner.
- 10.4.5** The finished coating shall be generally smooth and free of application defects such as pinholes, fisheyes, sags, drips, etc.
 - 10.4.5.1** Shall meet the specified DFT in accordance with SSPC-PA 2.
 - 10.4.5.2** Impact Resistance – ASTM G14 – greater than 20 in-lbf (2.26 Nm), no cracking or holidays.

10.5 Coating Repair

- 10.5.1** All coating defects should be repaired using owner-approved materials that are compatible with and adhere well to the base coating.
- 10.5.2** Repair materials normally consist of the same material used for the original repair, rehabilitation, or field joint coating or repair materials and methods recommended by the coating supplier.
- 10.5.3** Repairs to isolated coating holidays should overlap the surrounding coating a minimum of 13 mm (0.50 in).
- 10.5.4** The surface to be repaired should be clean, dry, and roughened in accordance with SSPC-SP 2, Hand Tool Cleaning, or in accordance with the coating manufacturer's recommendation. Adequate surface profile must be created to ensure mechanical adhesion of the repair material to the existing coating system.
- 10.5.5** Minimum thickness of the repaired coating shall be in accordance with the coating manufacturer's recommendations.

10.6 Handling

- 10.6.1** After the plate has been coated, the coating should be sufficiently cured to a dry-to-stack, dry-to-handle state prior to shipping.
- 10.6.2** Coated plate shall be handled in such a way that damage to the plate and/or coating is avoided.

Other Referenced Documents

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2. B. Bavarian, J. Zhang, L. Reiner, "SCC and Crevice Corrosion Inhibition of Steam Turbine ASTM A470 Steel," CORROSION 2012, paper no. 1070 (Houston, TX: NACE, 2012).
3. P. Shukla, X. He, O. Pensado, A. Nordquist, "Vapor Corrosion Inhibitors Effectiveness for Tank Bottom Plate Corrosion Control," PRCI Report Catalog No. PR-015-153602-R01. (Chantilly, VA: PRCI, Inc. 2018).
4. A. Khalil, P. Calvin, "Compatibility and Interactions between Cathodic Protection and a Vapor Phase Corrosion Inhibitor," CORROSION 2017, paper no. 9232 (Houston, TX: NACE, 2017).
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6. S. Math, P.K. Shukla, "Galvanic Anode Cathodic Protection System Performance in the Presence of Vapor Corrosion Inhibitors for Aboveground Storage Tank Application," CORROSION 2019, paper no. 12787 (Houston, TX: NACE, 2019).
7. P. Shukla, A. Nordquist, R. Fuentes, B. Wiersma, "Vapor Corrosion Inhibitors Effectiveness for Tank Bottom Plate Corrosion Control" Phase 2, PRCI Report Catalog Number PR644-183611-R01. (Chantilly, VA: PRCI, Inc. 2022).