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CORROSION CONSIDERATIONS FOR ABOVEGROUND ATMOSPHERE STORAGE TANKS

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ABSTRACT

Several American Petroleum Institute (API) Standards and Recommended Practices speak directly to the basic need to control corrosion of the bottom, shell, and roof of aboveground storage tanks (ASTs) to assure tank integrity. These documents contain information and requirements related to corrosion that must be considered for new tanks, in their design and construction, and for existing tanks during inspection, maintenance and repair activities. This paper reviews the requirements contained in these documents and presents histories of internal and external corrosion that has occurred in ASTs.

INTRODUCTION

AST corrosion continues to be a critical problem, not only in the petroleum process industry, but in other industries that store corrosive or environmentally sensitive materials or products in aboveground tankage. In the petroleum industry, AST corrosion is of concern at production, transportation, manufacturing, and marketing facilities. It is the objective of this paper to review several API Standards and Recommended Practices with emphasis on the requirements in these documents related to corrosion and corrosion control. These documents are:

- API Standard 650 – "Welded Steel Tanks for Oil Storage"
- API Recommended Practice 575 – "Inspection of Atmospheric and Low Pressure Storage Tanks"
- API Standard 653 – "Tank Inspection, Repair, Alteration, and Reconstruction"

The last two documents contain Inspection Checklists which are useful during external and internal inspection of tanks. These are provided as guidance for owners and operators in developing an inspection assessment program. Many of the inspection activities included on the checklists are there because of corrosion concerns. API Recommended Practice 575 also contains detailed discussions of corrosion mechanisms associated with ASTs that are accompanied by related photographs.

WHAT IS AN ABOVEGROUND STORAGE TANK?

The bottom of an AST consists of two separate sections, the central portion (referred to as bottom plate), and also, a sketch plate or an annular plate. The bottom plate is regarded as a membrane because it is continuously supported by the foundation and there is essentially no stress in it. The sketch plate or annular plate forms the perimeter of the tank bottom and supports the tank shell. The sketch or annular plate extends beyond the bottom-to-shell joint. Bottom and sketch plates are a minimum of 6.5 mm (0.25 in.) thick. The annular plate is generally much thicker, perhaps 13 mm (0.5 in.) or thicker. The tank bottom is generally sloped to facilitate drainage and referred to as cone bottom up or cone bottom down.

The tank shell height is divided into approximately 2.5 m (8 ft) high courses or rings for practical construction considerations. The rings are progressively thinner from the bottom to the top of the shell. The thickness is based upon mechanical considerations affected by hydrostatic loads at the various heights.

There are three major types of roofs: cone roof, external floating roof, and internal floating roof. Typical cone or external floating roof plate is 6.5 mm (0.25 in.) thick. An internal floating roof is often fabricated from aluminum. A geodesic dome, usually fabricated from aluminum, may be used in conjunction with an internal floating roof or as a replacement for a corroded cone roof tank. Figure 1 shows a very large, external floating roof, aboveground storage tank in crude oil service.

Frequently, the tank bottom, shell courses, and roofs are subject to both internal and external corrosion. The tank bottom is subject to soil-side corrosion and corrosion from within the tank. The shell and roof are subject to corrosion from within the tank and also, to atmospheric environmental corrosion. Tank bottom corrosion is discussed initially.

TANK BOTTOM CORROSION

API Standard 653 lists twelve causes of corrosion that may result in a tank bottom leak, and six of these are directly related to corrosion---both internal and external. The materials and construction of the foundation support pad play a major role in external corrosion. API 650, in the design of new storage tanks, contains specific recommendations to minimize such external corrosion and therefore, extend the life of the tank bottom, as discussed below.

Concerning the foundation, API Standard 650 recommends that the tank bottom should be 0.3 m (1 ft.) above grade as shown in Figure 2. This, directionally, promotes drainage away from the tank and hopefully minimizes accumulation of water beneath the tank bottom. API Standard 650 also recommends that the design of the foundation pad include the use of three to four inches of clean, washed sand beneath the tank bottom plate. Its purpose is to minimize future corrosion problems and also, increase the effectiveness of a Cathodic Protection (CP) system, if installed. The sand rests upon a sub-foundation of crushed stone and gravel. This fill is graded in progressively smaller sub-layers from top to bottom. At the perimeter of the tank, the shell/bottom plate juncture is commonly supported by a reinforced concrete ring wall or a crushed stone ring wall.

As pointed out previously, the bottom plate, if supported properly, is essentially a membrane and there is little stress. Therefore it may lose, because of corrosion, 60-80% of its design thickness before repairs are required. However, at the ring wall, the shell-to-bottom juncture is subjected to high bending stresses. Corrosion is of critical concern in this area and repairs may be required at this location before repair of the bottom plate is needed (i.e., less corrosion may be permissible in the sketch plate or annular ring than in the rest of the bottom). Thus, when evaluating tank bottom corrosion, these two sections of the bottom must be evaluated separately.

API Standard 653 and Bottom Plate Corrosion

API Standard 653 provides evaluation requirements that are used to develop long-term strategies to prevent tank leaks that may be environmentally damaging. These include, minimum acceptable bottom plate thickness. Therefore, evaluations must be undertaken to determine the extent of both topside and underside general corrosion and pitting. These evaluations are most frequently undertaken when the AST is not in service. The extent of corrosion and pitting are quantified by internal bottom inspection and externally, by statistical or deterministic methods. Both methods have been deemed accurate and have been used extensively; they depend upon determining the following data:

- Original plate thickness
- Years in-service
- Average and maximum depth of internal pitting
- Average and maximum depth of external pitting
- Average depth of general corrosion
- Elapsed time period until next internal inspection

Minimum Remaining Thickness (MRT) is defined in API 653 as the remaining thickness of the tank bottom plate at the end of the <u>next</u> in-service period of operation until the bottom is inspected again. MRT_1 is calculated based on average internal pitting and maximum external pitting, and MRT_2 is calculated based on maximum internal pitting and average external pitting. Both MRT_1 and MRT_2 include the appropriate general metal loss that will occur during the next in-service period of operation. Figure 3 is a photograph of soilside corrosion occurring on tank bottom plate.

At the end of the next scheduled in-service period, MRT_1 and MRT_2 cannot be less than 2.5 mm (0.10 in.) for a bare steel bottom, and 1.25 mm (0.05 in.) for a bottom protected with an appropriate Fiberglass Reinforced Plastic (FRP) lining or equipped with an undertank leak detection system. Several designs for leak detection systems are contained in Appendix I to API Standard 650. In-service periods can be extended by various means such as repairing the deepest pits, replacing or patching portions of the bottom, adding cathodic protection, adding a liner, or a combination of actions. Owners are now striving for 20 year in-service periods. This means increased emphasis on using <u>proven</u> corrosion prevention systems.

Corrosion in the "Critical Zone"

The "Critical Zone" of the tank bottom is defined by API Standard 653 as being within three inches of the inside edge of the shell measured radially inward on the sketch plate or annular plate. As noted previously, this portion of the tank bottom is supported by a concrete ring wall or crushed stone ring wall and it may be highly stressed. Therefore, internal and external corrosion control in this region is of great importance. This becomes critical as discussed in subsequent paragraphs.

The allowable minimum thickness of a sketch plate (6.5 mm [0.25 in.) original thickness) is 2.5 mm (0.10 in.) and there is no allowance for an internal lining or an under tank leak detection system. There are generally more stringent requirements for the thicker, butt-welded, annular plate. An annular plate is used in large diameter storage tanks and in those located in areas of known seismic activity. In all cases, the minimum required annular plate thickness in the critical zone is greater than the acceptable bottom or sketch plate thickness of 2.5 mm (0.10 in.) The allowable thickness is specified on the basis of the original thickness of the first shell course and the stress in the first shell course. As an example, for a tank where the first shell course thickness is 1.9 mm (0.75 in.) or less and has a stress of 24,300 psi, the annular plate thickness in the critical zone must be 4.25 mm (0.17 in.) or greater.

The dilemma here is that corrosion occurring on the underside of the tank bottom resting on a concrete or crushed stone ring wall will probably not be identical to that occurring over the rest of the tank bottom. It is accepted that a cathodic protection system will not be effective at the juncture of the shell/bottom plate because of the concrete ring wall. Also, it is at times reported that CP is not effective on the bottom plate adjacent to the concrete wall because of voids often found along the inside of the concrete wall. Severe corrosion can also occur in this area where a crushed stone ringwall is used. Mounding around the perimeter of the tank may result because of tank settlement which will trap rain water. This is shown in Figure 4 and discussed below.

Rainwater that runs down the tank shell will find its way beneath the tank shell and will cause corrosion in the "critical zone" no matter which ring wall is used. This is of major concern because inspection in this area is usually not possible until the tank is emptied and out-of-service. However, the underside corrosion near the bottom/shell juncture can be difficult to detect and measure even with the tank out-of-service and opened for inspection, so special precautions are often made.

To minimize such underside corrosion, some owners provide positive rain shelters and others provide sloped mastic or bituminous-impregnated hot applied tapes in order to externally seal the juncture of shell/bottom plate to prevent rainwater migration. See Figure 5. In API Standard 650, as an option, an asphalt-impregnated board is shown placed under the perimeter during tank construction.

Corrosion of the Bottom Plate Extension

The third concern is severe corrosion of the portion of the tank bottom that extends outside of the tank shell which is shown in Figure 6. API Standard 653 states that this extension cannot be less than 2.5 mm (0.10 in.) thick and the remaining projection of the bottom plate, measured at the toe of the outside bottom-to-shell fillet weld, shall be at least 9.5 mm (0.375 in.) thick. The original length of this protection is one inch minimum for sketch plates and two inches for annular plates. There are several causes for corrosion of this extension. These include: rainwater running down the side of the tank and finding its way under the tank, mounding around the tank, and corrosion under the shell thermal insulation system extends to the bottom of the tank so that this section of the tank cannot be inspected.

Cathodic Protection (CP) and API Standard 653

Before leaving bottom plate external corrosion, it should be noted that API Standard 653 recommends that the performance of the CP system be checked periodically by the schedule recommended by API Recommended Practice 651, "Cathodic Protection of Aboveground Storage

Tanks." This practice recommends that the electrical components of an impressed current CP system be inspected and output readings recorded bimonthly. At yearly intervals, there should be a complete CP systems survey. This should be undertaken by an "accredited" CP specialist or equivalent.

The writer supports the above practices, but would add that the design and installation of the system should be as specified in NACE Recommended Practice RP0195, "Cathodic Protection of Above Grade Atmospheric Storage Tanks." It should be kept in mind that CP systems that are properly designed and installed will not protect the external tank bottom if the foundation is poorly specified or properly specified but installed without adequate inspection. Severe pitting corrosion has been encountered on cathodically protected tanks because small clumps of clay or stone that have not been removed from the foundation pad during construction.

TANK SHELL AND ROOF CORROSION

The next section of this paper will review those issues discussed in the API documents which relate to corrosion of the storage tank shell and roof. API Standard 653 requires both in-service and out-of-service inspections of the roof and shell with much of the emphasis in these inspections directed at corrosion and materials degradation. In-service evaluations are first reviewed.

Storage Tank Shell and Roof In-Service Inspection

Both API Standard 653 and API Recommended Practice 575 extensively discuss corrosion of the shell and roof of aboveground storage tanks and specifically recommend inspection intervals and the type of inspection to be employed. Two types of external inspections are specified, which are discussed below; the types of corrosion most likely to be encountered are highlighted.

The <u>first</u> external in-service inspection activity described may be undertaken by the owner or operator at an interval not exceeding one month. It is essentially a "walk-around" visual inspection of the exterior surface checking for leaks, corrosion, paint coating condition, insulation system condition, or signs of deterioration of the storage tank foundation. This inspection does not need to be undertaken by certified inspectors, and it is usually done by operations personnel during the course of their normal work.

The <u>second</u> external in-service inspection includes an ultrasonic thickness inspection survey of the shell and the roof to determine the general internal corrosion rate of the shell. This is specified to be undertaken at a maximum 5-year interval. Insulated tanks must have the insulation removed to the extent necessary to determine the condition of the exterior shell and roof, as well as to make the required thickness measurements. This inspection is required to be undertaken by an "authorized" inspector.

The "External Inspection" check list is extensive and there are numerous specific items related to corrosion and materials deterioration including:

- Inspection for paint failure, pitting, corrosion of roof and shell.
- Cleaning and inspection of the shell/bottom plate juncture bottom angle.
- Inspection of bottom foundation seal.
- Inspection of wind girders.
- Inspection of the condition of the thermal insulation system, if installed on the roof and shell.
- Removal of insulation on roof and shell to inspect the underlying steel.
- Visual inspection of the upper shell courses of floating roof tanks when exposed.
- Shell and roof ultrasonic thickness measurements.

There are no specific guidelines concerning the location and frequency of ultrasonic shell inspection. They are frequently made from the tank stairway or ladder on each shell course. Remote ultrasonic thickness, measurement tools are also available. These are commonly used when more extensive thickness measurements are needed. Of the approximate 100 items listed on the in-service check-list, approximately one third of them deal with corrosion or materials degradation.

Storage Tank Shell and Roof Out-of-Service Inspection

The internal inspection of the shell and roof is undertaken during the same time as the tank bottom is inspected. All internal inspections are also required to be undertaken by an authorized inspector. The shell and roof inspections include all the same items as the in-service external inspection but in much more detail. The additional internal inspections include:

- Measurement of pitting and local corrosion on each shell course.
- Metal loss in the lower 10-15 cm (4-6 in.) of the shell.
- Any protective lining on the shell, bottom or roof.
- Underside of roofs for holes, corrosion, or pitting.
- Cracking of roof welds.
- Support columns in upper 0.6 m (2 ft) for thinning.
- Check reinforcing pads for roof columns and landing legs for corrosion or buckling.
- Inspect roof rafters for corrosion.
- Inspect each pontoon in floating roof for weld integrity and seal welds.
- Inspection of all internal equipment and piping.

The above is a brief sampling of the internal out-of-service checklist activities needed to establish the integrity of an AST.

Storage Tank Shell Corrosion

API Standard 653 addresses both general and pitting corrosion of the shell. If there is general shell corrosion, the acceptable minimum plate thickness for each shell course is based upon maximum allowable stress, tank size, and other considerations. Also, any needed corrosion allowance required during the next in-service period must be considered. A complicating factor is that the general corrosion rate may not be identical in each shell course, or even at different locations within the same shell course. As an example, for an external floating roof tank in light product service, corrosion is often more severe in the upper and middle courses. See Figure 7. Another complication is that the original shell thickness varies, as discussed previously, from the top of the tank to the bottom.

API Standard 653 states that scattered deep pitting of the shell can be ignored so long as no pit is deeper than $^1/_2$ of the minimum acceptable shell thickness minus corrosion allowance. Another requirement is that the sum of the pit dimensions along any vertical line eight inches long should not exceed two inches. And again, of course, additional pitting corrosion during any future in-service period must also be considered. It should be kept in mind that there may be deep internal pitting in the 15-20 cm (6-8 in.) lower section of the bottom shell course. This occurs because of the water bottom found in many storage tanks. Also, deep scattered pitting is frequently encountered beneath thermal insulation which cannot be detected unless the thermal insulation is removed.

Storage Tank Roof Corrosion

API Recommended Practice 575 contains a detailed discussion concerning storage tank roof corrosion for fixed and floating roofs. In this regard, aggressive internal and external corrosion has long been a problem on tank roofs. There is a general statement in API Standard 653 that "roof plates corroded to an average thickness of 2.25 mm (0.09 in.) in any 625 square cm (100 square in.) area, or roof plates with any holes, shall be repaired or replaced." For comparison, new roof plate is generally 6.5 mm (0.25 in.) thick.

External roof corrosion may occur because of atmospheric corrosion that is more severe than that which would occur on the shell. This is illustrated in Figure 8. This is caused by almost constant exposure to sunlight and increased time-of-wetness because of ponding of rainwater on both cone and floating roof tanks. The protective coating system applied to a tank roof should have weathering properties that are superior to that which is applied to the shell. It is not unusual when performing a maintenance-point survey to determine that roofs are in more need of repainting than the tank shell. Tank roofs that are thermally insulated require special consideration because corrosion may occur beneath the insulation without any external indication. See Figure 9. API Recommended Practice 575 states that before assessing the roof, check the thickness or lightly use a ball peen hammer at the edge of the roof to test for thinning where internal corrosion is most severe.

Internal corrosion can be particularly severe on the underside of cone roof tanks and their supporting structure, depending upon the product stored and the environmental conditions. In marine atmospheres, moist salt air can enter the tank vapor spaces during normal operation. Any sour stocks may cause accelerated corrosion. Cone roof replacements are not unusual; an aluminum geodesic dome is often used as a lower cost alternative to replacing a carbon steel cone roof.

CONCLUSIONS

A review of the referenced API recommended practices and standards highlights the need for corrosion control to maintain the integrity of aboveground storage tanks. These present detailed discussions of requirements for both in-service and out-of-service evaluations of the effect of corrosion damage. The requirements and guidelines contained in these documents should be used as the basis for developing an AST inspection and integrity-assessment program.

When aggravated corrosion is encountered, detailed mechanical analysis of remaining strength may be required in order to evaluate the structural integrity of the tank and to develop long-term solutions. Basic decisions, however, are required concerning corrosion control measures during the initial design and fabrication of storage tanks. These include the following:

- What corrosion allowance is required for the bottom and shell of the storage tank? In API 650, there are no stated requirements for corrosion allowance; that decision is left to the owner.
- Should a protective lining be applied to the tank bottom and/or shell? Should the bottom lining be a reinforced thick lining or a thin film lining?
- How does the cost of an internal lining compare to an increase in bottom plate thickness?
- Is cathodic protection required, and if so what type of design should be employed?
- For the external roof, especially of external floating roof tanks, what protective coating system is needed?
- If the tank shell is to be thermally insulated, how should the system be designed and is there a need for a protective coating system applied to the shell? Also, more critical is if the roof is insulated--what system should be used and how is it to be protected from atmospheric weathering?

In the writers' opinion, there is much to be learned from the API documents discussed in this paper. One of the basic lessons is that many skills are needed to properly assess corrosion and corrosion damage in an aboveground storage tank. These include corrosion/materials specialist, structural/mechanical engineer, accredited tank inspectors, not to mention specialists in NDT, protective coatings and linings, and cathodic protection. Use of such a multi-disciplinary approach to storage tank design and maintenance will achieve increased reliability in a cost-effective manner.

REFERENCES

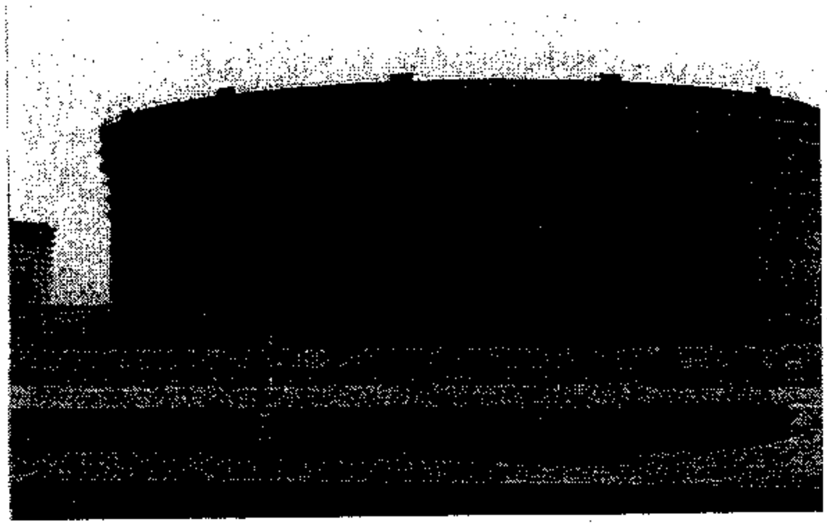
1. API Standard 650 – "Welded Steel Tanks for Oil Storage," American Petroleum Institute, Washington, D.C.

2. API Recommended Practice 575 – "Inspection of Atmospheric and Low Pressure Storage Tanks," American Petroleum Institute, Washington D.C.

3. API Standard 653 – "Tank Inspection, Repair, Alteration and Reconstruction," American Petroleum Institute, Washington, D.C.

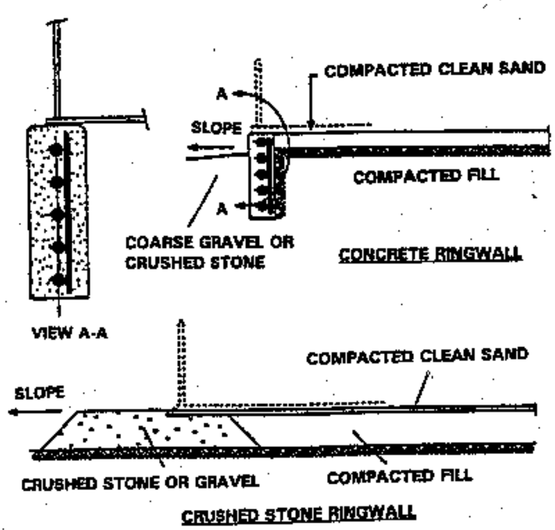
4. API Recommended Practice 651 – "Cathodic Protection of Aboveground Storage Tanks," American Petroleum Institute, Washington, D.C.

5. NACE Recommended Practice RP0195 – "Cathodic Protection of Above Grade Atmospheric Storage Tanks," NACE International, Houston, Texas.



<u>Figure 1</u>

A photograph of a million barrel floating roof crude oil storage tank located in a very severe marine environment that experiences several typhoons each year. Note the number of wind girders. It is externally protected with one coat of a water based inorganic zinc rich coating.



<u>Figure 2</u>

Schematic of a concrete ringwall and also a crushed stone ringwall which is described in API Standard 650.

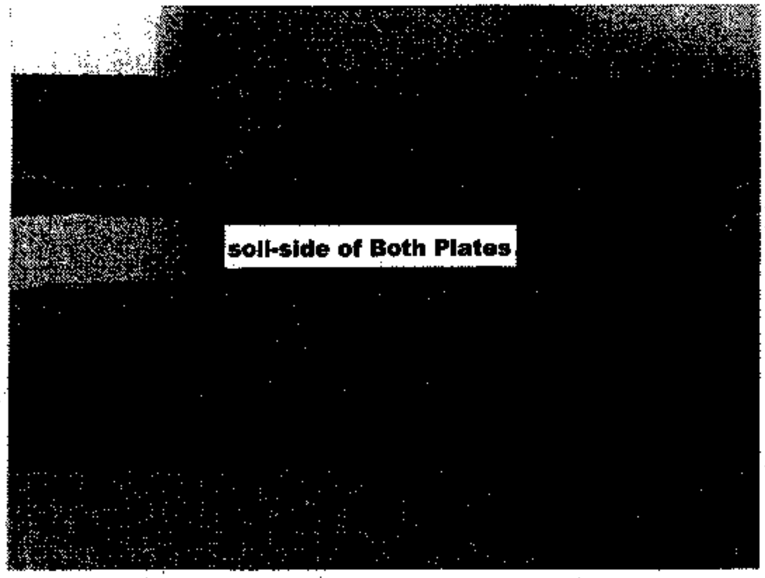


Figure 3

A photograph of external tank bottom pitting corrosion with corrosion scale actually blocking an external pit that has perforated the tank bottom plate.

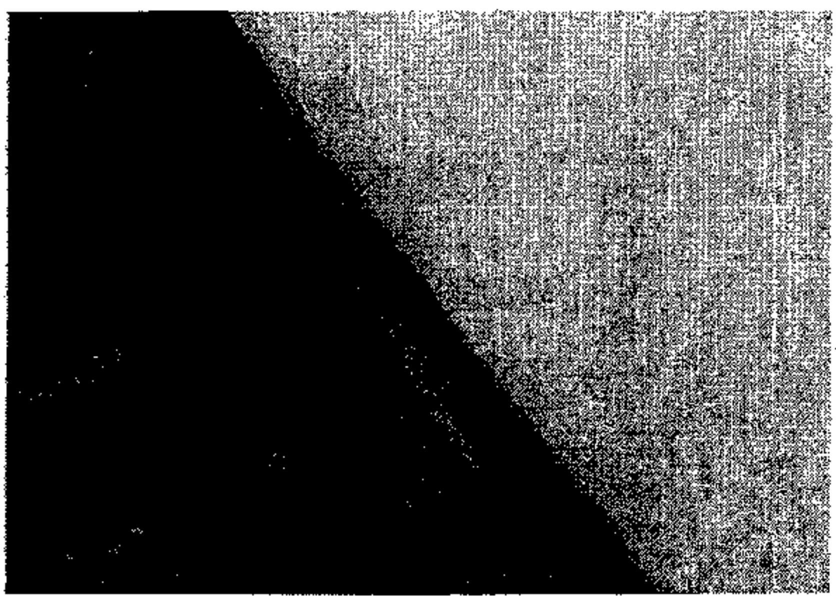


Figure 4

Tank settlement has caused mounding around the storage tank perimeter and corrosion around the perimeter of the tank has taken place.

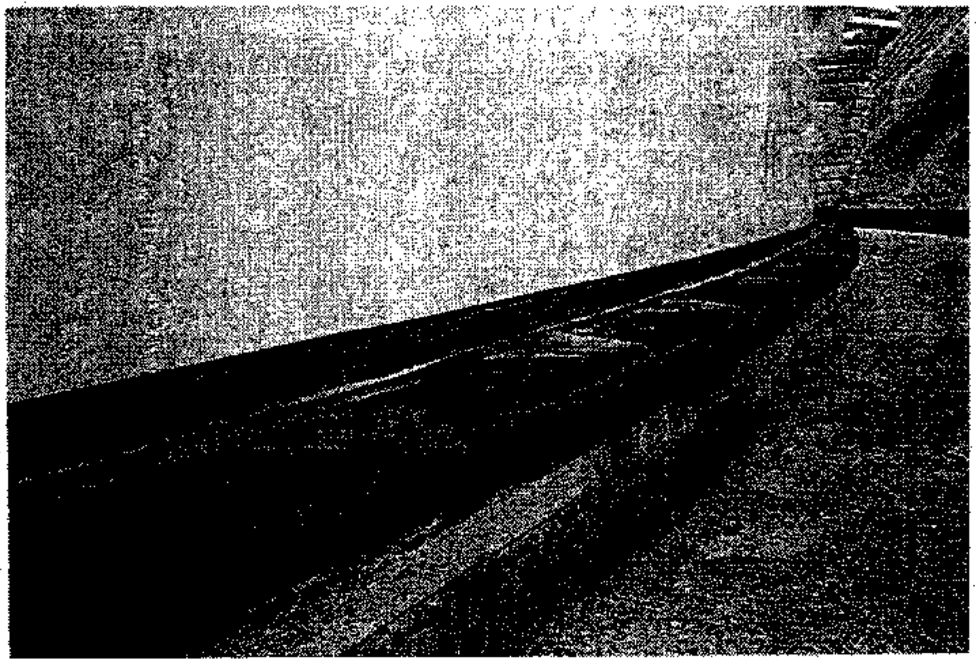


Figure 5

A hot applied bituminous roof felt was applied to the perimeter of the tank and across and down the concrete ringwall to prevent rainwater migration beneath the tank bottom.

Figure 6

Corrosion of the bottom plate extension is shown in this photograph. This occurred on a thermally insulated tank that employed cellular glass block. Cellular glass has been used unsuccessfully in the past to prevent such corrosion. The insulation system should be terminated 12 in. above the tank bottom and this area properly coated.

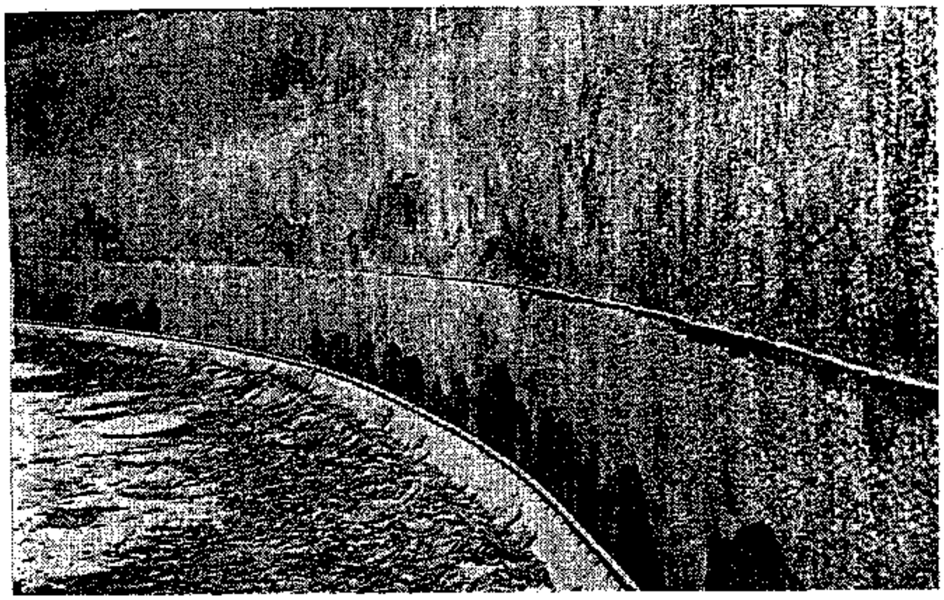


Figure 7

Photograph illustrating internal shell corrosion of an external floating roof storage tank in light product service. Linings are frequently applied to prevent internal shell corrosion and/or protect product quality.

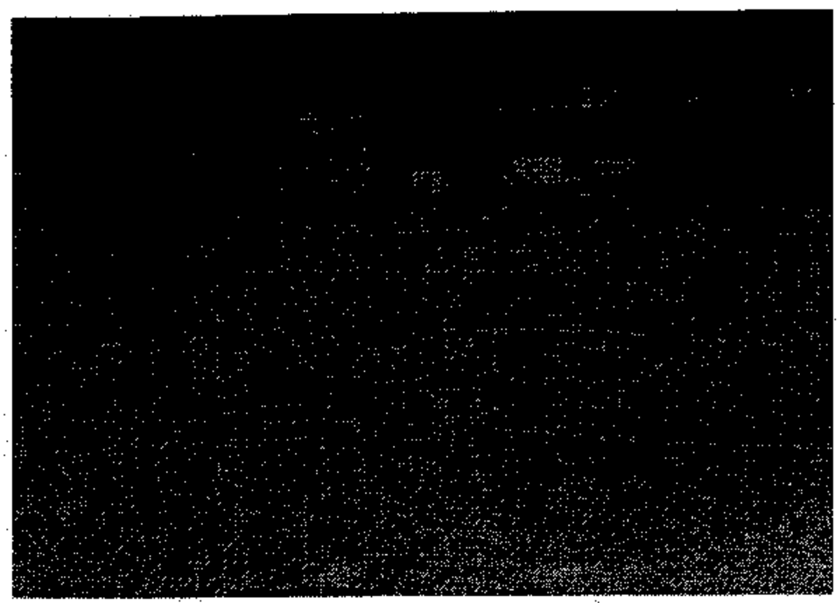


Figure 8

Aggressive atmospheric corrosion has occurred on this cone roof tank. It was caused by failure of the protective coating system which was not properly specified for the marine environment.

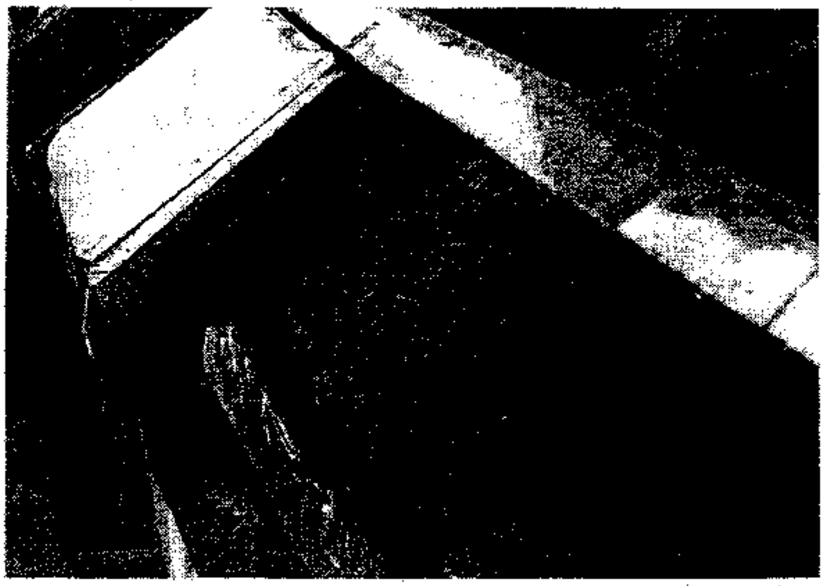


Figure 9

Aggressive corrosion has occurred beneath the cellular glass insulation system because of inadequate maintenance of the vapor barrier protective coating system, and also because the steel roof was not coated. This tank is in cold service.