

# **Guide for Inspection of Refinery Equipment**

## **Chapter XIII—Atmospheric and Low-Pressure Storage Tanks**

**Refining Department**

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## PREFACE

This chapter is one of a series which make up the manual, *Guide for Inspection of Refinery Equipment*. It is based on the accumulated knowledge and experience of engineers of the petroleum industry. All users are invited to submit suggested revisions to the director of the Refining Department, American Petroleum Institute, 1220 L Street, N.W., Washington, D.C. 20005.

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It is recognized that portions of this guide may be useful in the inspection of tanks used by production, petrochemical, and other segments of the oil and gas industry. Use of the applicable provisions of this guide in services other than refinery service is encouraged. Users of this publication are reminded that no book or manual is a substitute for the judgment of a responsible engineer or supervisor.

The *Guide for Inspection of Refinery Equipment* is subdivided as follows:

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| Chapter I     | Introduction                                       |
| Chapter II    | Conditions Causing Deterioration or Failures       |
| Chapter III   | General Preliminary and Preparatory Work           |
| Chapter IV    | Inspection Tools                                   |
| Chapter V     | Preparation of Equipment for Safe Entry and Work   |
| Chapter VI    | Pressure Vessels (Towers, Drums, and Reactors)     |
| Chapter VII   | Heat Exchangers, Condensers, and Cooler Boxes      |
| Chapter VIII  | Direct-Fired Boilers and Auxiliary Equipment       |
| Chapter IX    | Fired-Heaters and Stacks                           |
| Chapter X     | Pumps, Compressors, and Blowers, and Their Drivers |
| Chapter XI    | Pipe, Valves, and Fittings                         |
| Chapter XII   | Foundations, Structures, and Buildings             |
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# Guide for Inspection of Refinery Equipment

## CHAPTER XIII—ATMOSPHERIC AND LOW-PRESSURE STORAGE TANKS

### 13.1 Types of Storage Tanks

#### 13.1.1 GENERAL

Storage tanks in refineries are used to store crude oil, intermediate and refined products, gas, chemicals, and water. Important factors, such as the volatility of the stored material and the desired storage pressure, result in tanks being built in different types and sizes and of various construction materials. In this chapter only atmospheric and low-pressure storage tanks have been considered. The construction and inspection of high-pressure tanks designed to operate at pressures of more than 15 pounds per square inch gage are more closely related to that for pressure vessels; hence such tanks are considered in Chapter VI, "Pressure Vessels."

##### 13.1.1.1 Linings

Where corrosion is experienced or expected, tanks can be lined with a corrosion-resistant material such as epoxy, vinyl, or zinc-rich coatings; fiberglass reinforced plastics; poured or gunned concrete; lead; alloy steel; aluminum; rubber; or glass.

##### 13.1.1.2 Auxiliary Equipment

Most storage tanks are provided with special auxiliary equipment, such as liquid-level gages, pressure-relieving devices, vacuum venting devices, gaging hatches, roof drains, and mixing devices. Stairways, ladders, platforms, handrailing, pipe nozzles, manholes, and, if necessary, electric grounding connections are considered part of the auxiliary equipment of storage tanks. Tanks may be externally insulated to keep heat in or out.

#### 13.1.2 ATMOSPHERIC STORAGE TANKS

Atmospheric storage tanks are those tanks that have been designed to operate in their gas and vapor spaces at internal pressures which approximate atmospheric pressure. Such tanks are usually constructed of carbon or alloy steel, or other metals for special services; however, they can be constructed of concrete or glass-reinforced epoxy plastic. Some wood tanks constructed to API Specification 12E are still in service. Atmospheric storage tanks are

generally welded or bolted, but some riveted tanks constructed to API Standard 12A are still in service. Specifications for the construction of atmospheric storage tanks are given in the following API standards:

Std 12A *Specification for Oil Storage Tanks with Riveted Shells*, Seventh Edition, 1941 (Reissued September 1951) and earlier editions

Std 12B *Specification for Bolted Tanks for Storage of Production Liquids*

Std 12D *Specification for Field Welded Tanks for Storage of Production Liquids*

Std 12E *Specification for Wooden Production Tanks*, out-of-print

Std 650 *Welded Steel Tanks for Oil Storage*

##### 13.1.2.2 Use of Tanks

Atmospheric storage tanks are used for the storage of materials having a true vapor pressure at storage temperature which is substantially less than atmospheric pressure. Vapor pressure is the pressure on the surface of the liquid caused by the vapors of that liquid. Vapor pressure varies with temperature, inasmuch as that more of the liquid vaporizes as the temperature rises. Crude oil, heavy oils, gas oils, furnace oils, naphtha, gasoline, and nonvolatile chemicals are usually stored in atmospheric storage tanks. Many of these tanks are protected by pressure vacuum vents which maintain the pressure difference between the tank interior and the outside atmosphere at less than a few ounces per square inch.

##### 13.1.2.3 Types of Tanks

There are many types of atmospheric storage tanks. The simplest type is the cone-roof tank, shown in Figure 1, which can reach 300 feet in diameter and 64 feet in height. In the larger diameter tanks, the roofs are supported by internal structural members. The umbrella-roof tank, shown in Figure 2, and the dome-roof tank are modifications of the cone-roof tank. In the dome-roof tank, the roof plates are usually formed with spherically curved segments joined to be self-supporting. The umbrella roof has segmental plates arched on meridian centerlines. Both the umbrella-roof and dome-roof tanks are rarely larger than 60 feet in diameter.

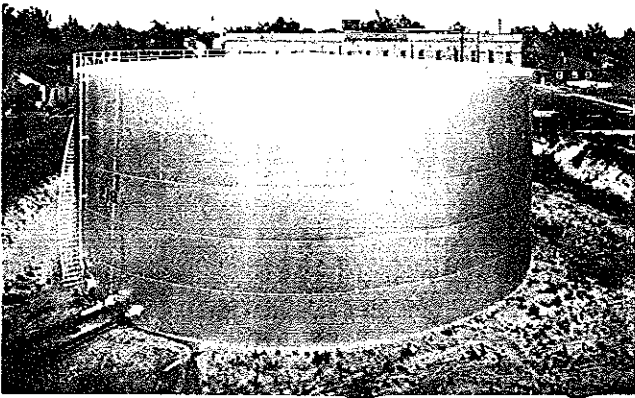


Figure 1—Cone-Roof Tank

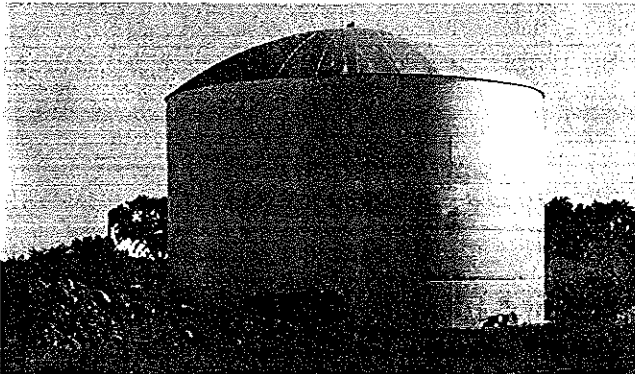


Figure 2—Umbrella-Roof Tank

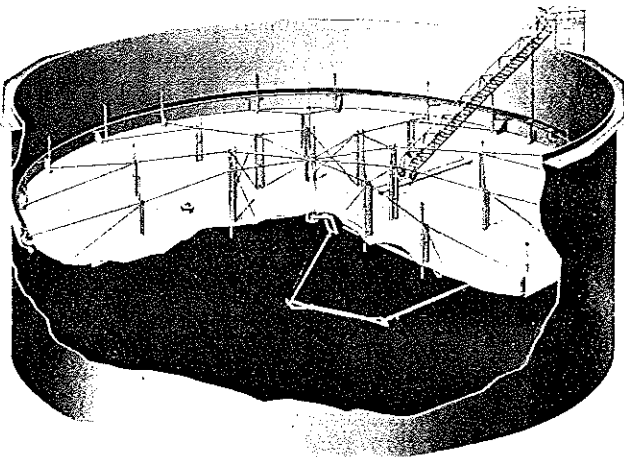


Figure 3—Pan-Type Floating-Roof Tanks

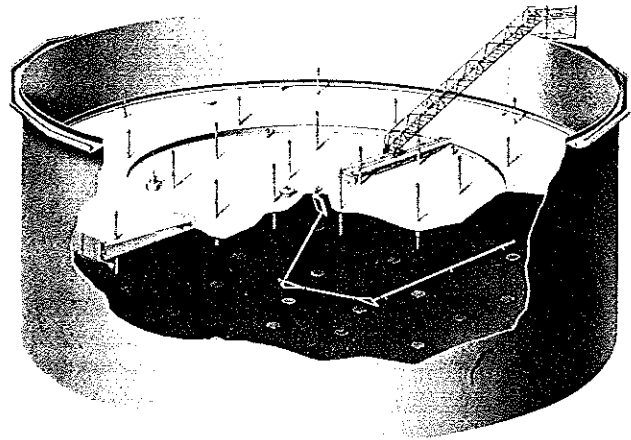


Figure 4—Annular-Pontoon Floating-Roof Tank

The floating-roof tank is another common atmospheric tank. This tank is designed to reduce filling and breathing losses to a minimum by eliminating or constantly maintaining the vapor space above the stored liquid. The shell and the bottom of this tank type are built similarly to cone-roof tanks but the roof is designed to float on the surface of the stored liquid. The simplest type of floating roof is the pan type, shown in Figure 3. Modifications of the simple pan-type floating roof are the annular-pontoon and the double-deck types, shown in Figures 4 and 5. Cross-sectional sketches showing the most important features of floating roofs are shown in Figure 6. Floating-roof tanks seal the space between the tank wall and the movable roof normally by a shoe or scuff plate which is pressed tightly against the tank wall by weights or springs, with a flexible membrane attached between the shoe and the roof deck.

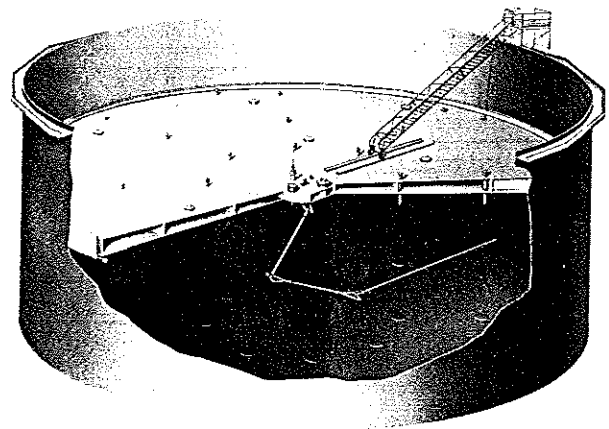
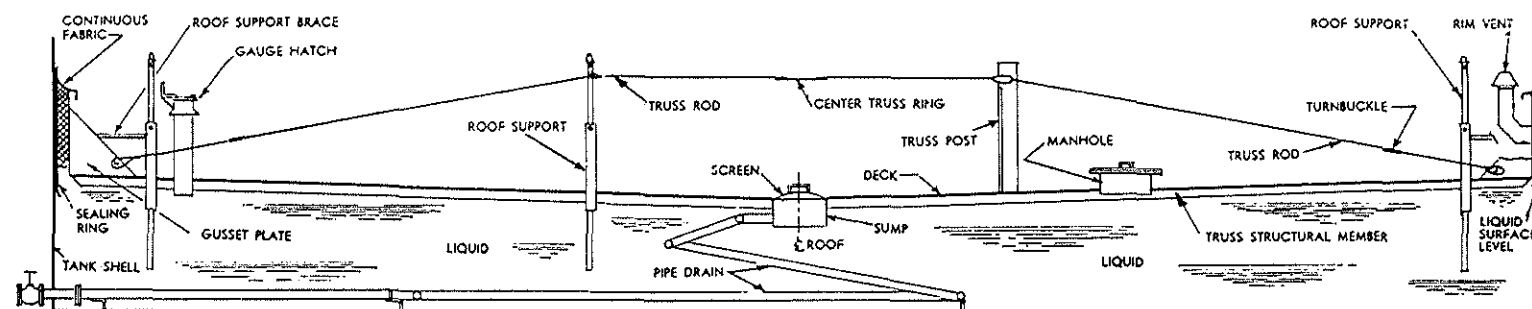
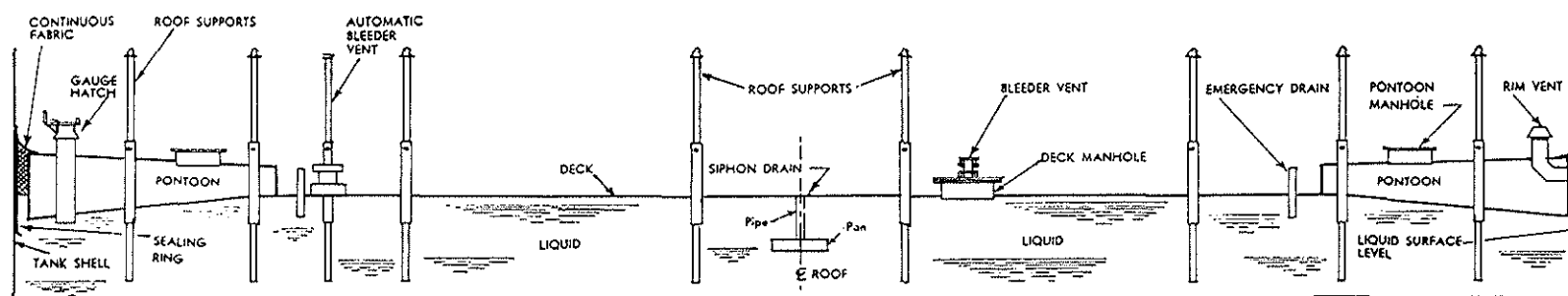


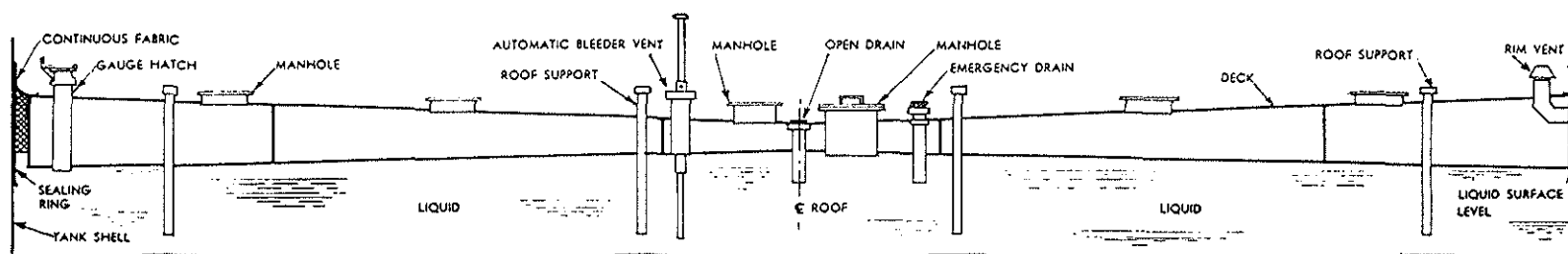
Figure 5—Double-Deck Floating Roof Tanks



PAN FLOATING ROOF



PONTOON FLOATING ROOF



DOUBLE DECK FLOATING ROOF

Figure 6—Cross-Section Sketches of Floating-Roof Tanks Showing the Most Important Features

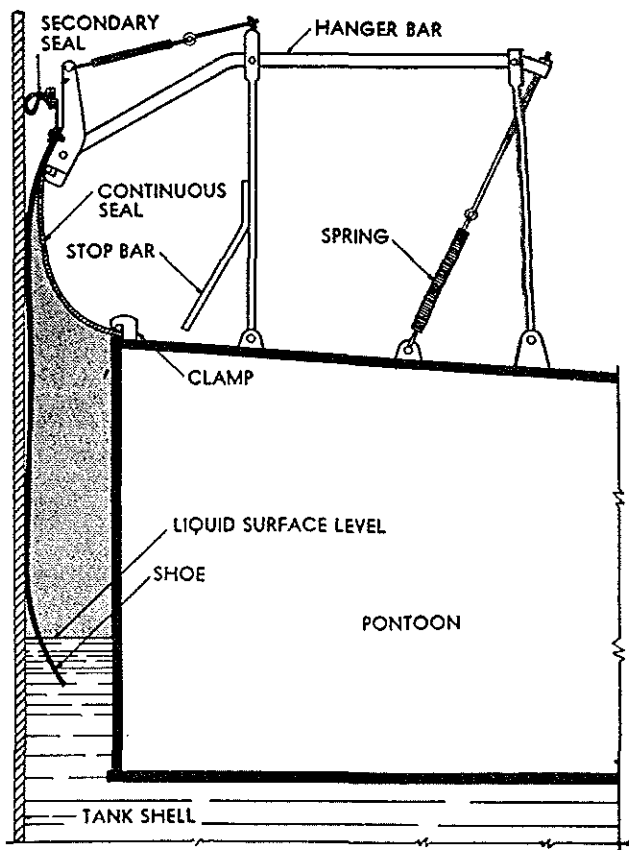


Figure 7—Floating-Roof Seal Using Coil Springs to Maintain the Seal

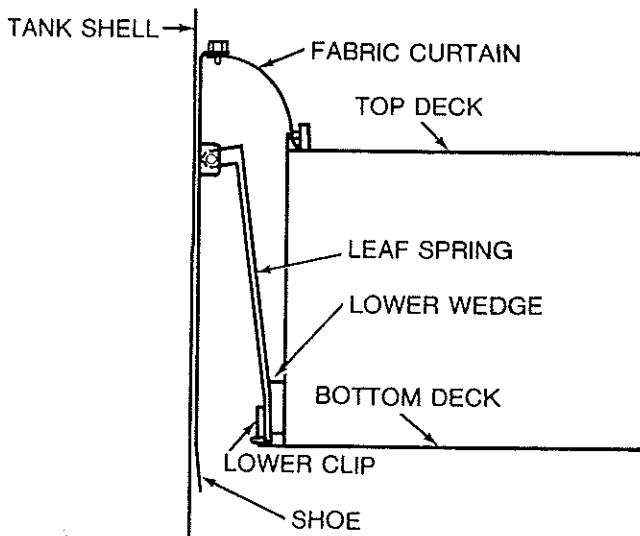


Figure 8—Floating-Roof Seal Using Leaf Springs to Maintain the Seal

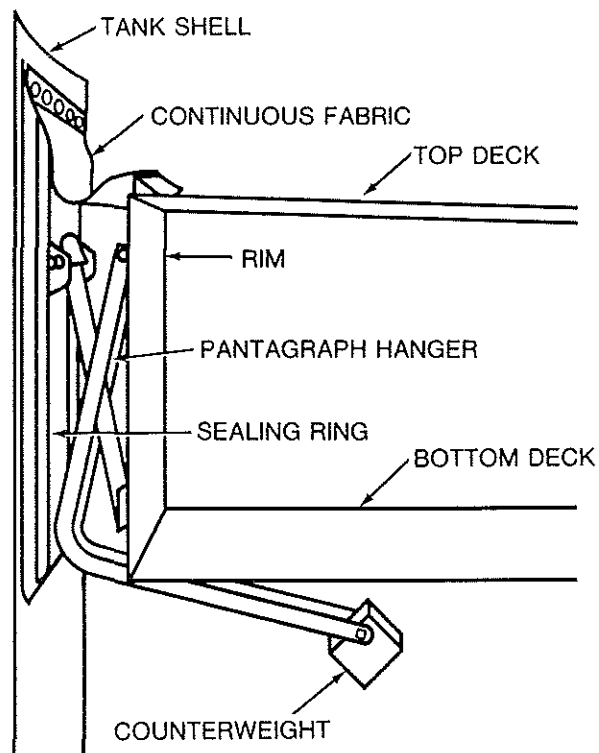


Figure 9—Floating-Roof Seal Using Counterweights to Maintain the Seal

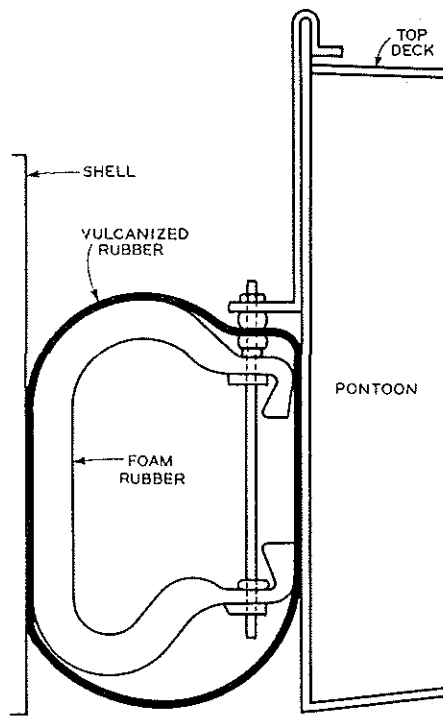


Figure 10—Floating-Roof Using Resilient Tube-Type Seal

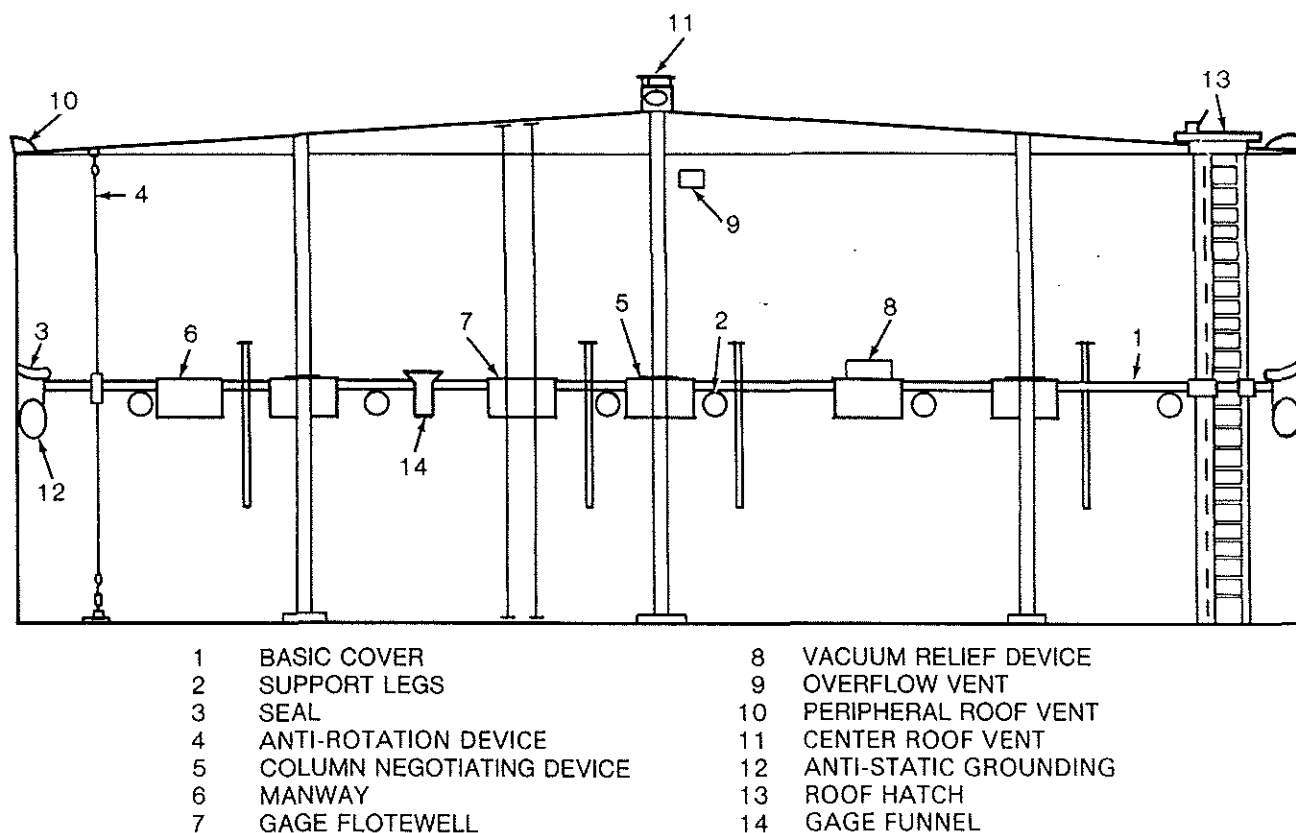


Figure 11—Typical Sandwich Internal Floating Roof for API Storage Tank

Typical examples of floating-roof seals are shown in Figures 7, 8, and 9. Another type of seal is the tube seal shown in Figure 10. These tubes are filled with solid foam, liquid, or air. Figures 11, 12, and 13 illustrate various pontoon roofs and seals.

Another type of tank is one with a fixed roof plus an interior pan floating roof. The fixed roof is usually a cone; the internal roof is called an internal floating roof and can be constructed of steel, aluminum, plastic, or other material (see Figure 11). Such tanks are usually built in areas where large snowfalls or rainfalls might endanger an open-top floating roof. An existing fixed-roof tank can be economically fitted with some type of internal floating roof. Covered floating roofs closely resemble pan-type roofs without trusses or drains.

Appendix H of API Standard 650 classifies internal floating roofs into the following types:

1. Metallic pan roof (in contact with the liquid and having a peripheral seal).
2. Metallic bulkhead roof (in contact with the liquid and having open-top bulkheads).

3. Metallic pontoon roof (in contact with the liquid and having closed pontoons).

4. Metallic double deck roof (in contact with the liquid).

5. Metallic roof on floats (deck above liquid).

6. Metallic sandwich panel roof (honeycomb panels with surface coating and in contact with the liquid).

7. Plastic sandwich panel roof (rigid panels with surface coating and in contact with the liquid).

Other less commonly used atmospheric storage tanks include the lifter-roof type, the breather-roof type, and the miscellaneous small cylindrical types. In the lifter-roof type, vapor losses from the tank are prevented by means of liquid or dry seals. In the liquid-seal roof, a skirt on the roof edge fits into a trough filled with liquid. In the dry-seal roof a flexible membrane is connected between a skirt on the roof edge and the tank wall. In the last two types, the roof is free to move up and down within limits as the tank is filled and emptied or when the temperature might cause vaporization of the stored product.

In the breather-roof type, a number of methods are used to provide expansion space for vapors without using a

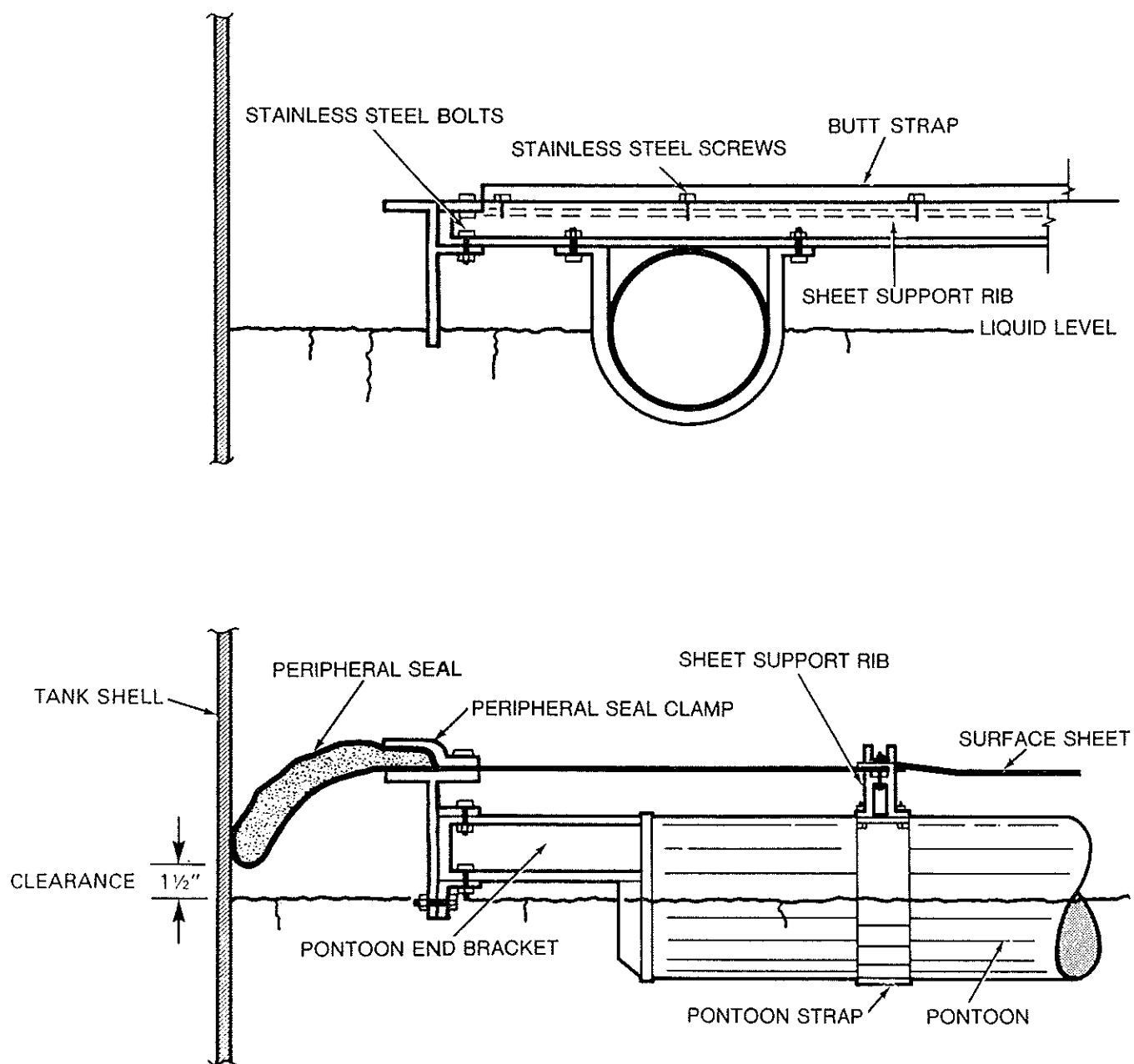


Figure 12—Typical Seal Arrangement for Metallic Float Internal Floating Roof

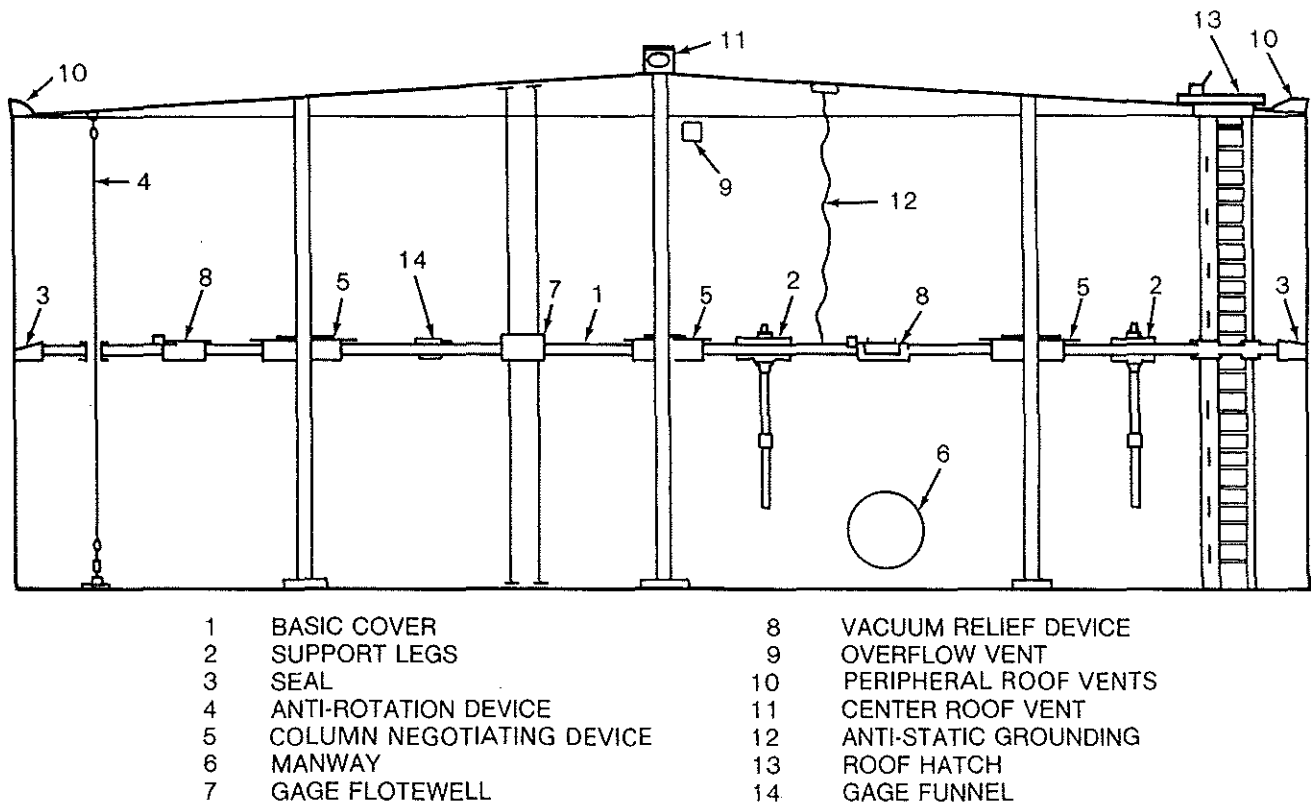


Figure 13—Typical Pan Type for Internal Floating Roof for API Storage Tank

loose external roof. The plain breather-roof tank, shown in Figure 14, has a flat roof that is essentially a flexible steel membrane capable of moving up and down within rather narrow limits. The balloon-roof tank, shown in Figure 15, is a modification of the plain breather-roof tank that is capable of a greater change of volume. The tank with vapor-dome roof, shown in Figures 16 and 17, uses an added fixed dome in which a flexible membrane is attached to the walls and is free to move up and down. This latter type can be designed to provide for any desired change in volume.

Plain cylindrical tanks, usually with flat heads or covers, can be used for the storage of small quantities of material at atmospheric pressure. These tanks can be placed in either the vertical or horizontal position. Horizontal tanks are shown in Figures 18 and 19.

### 13.1.3 LOW-PRESSURE STORAGE TANKS

#### 13.1.3.1 General

Low-pressure storage tanks are those designed to operate at pressures in their gas or vapor spaces exceeding those permissible in API Standard 650, but not exceeding

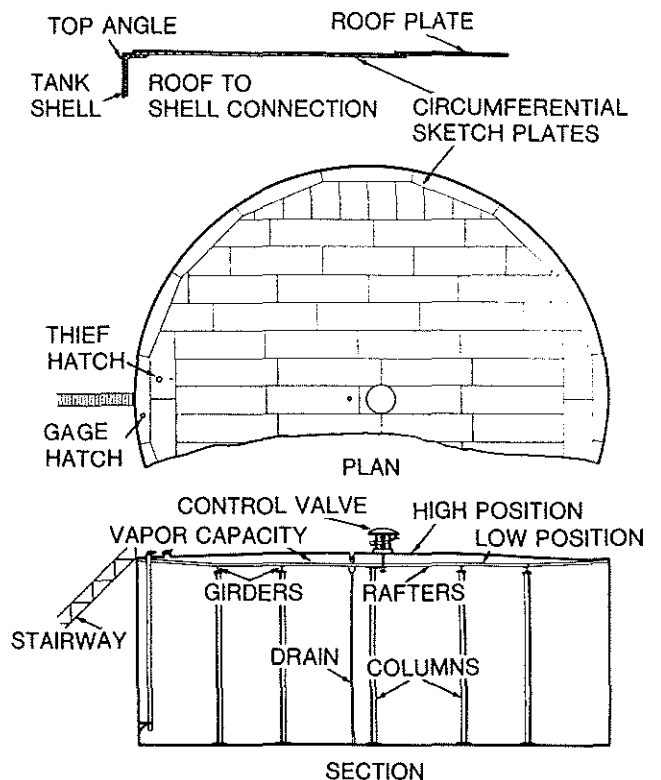


Figure 14—Plain Breather-Roof Tanks

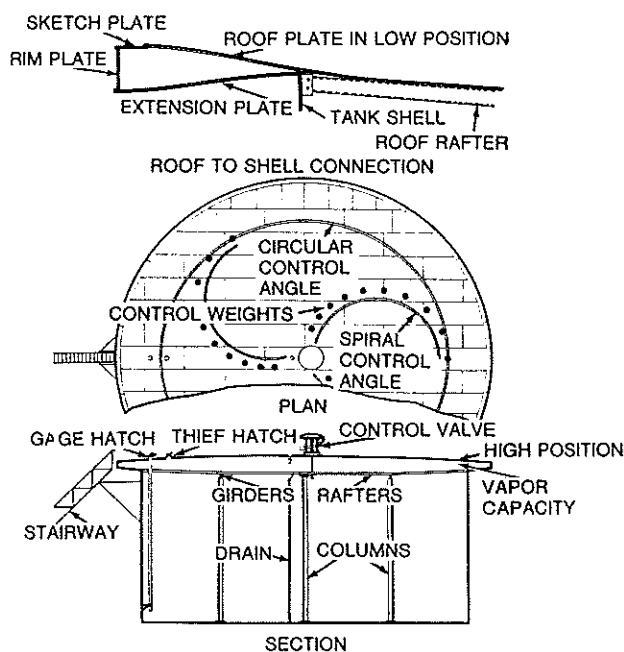


Figure 15—Balloon-Roof Tank

15 pounds per square inch gage. These tanks are generally constructed of steel and are usually welded, although riveted tanks are still in service. Rules for the construction of large, welded, low-pressure tanks are given in API Standard 620, *Recommended Rules for Design and Construction of Large, Welded, Low-Pressure Storage Tanks*. Low-pressure tanks can be, and are, constructed in general accordance with unfired pressure vessel codes except that higher allowable design stress values are normally used.

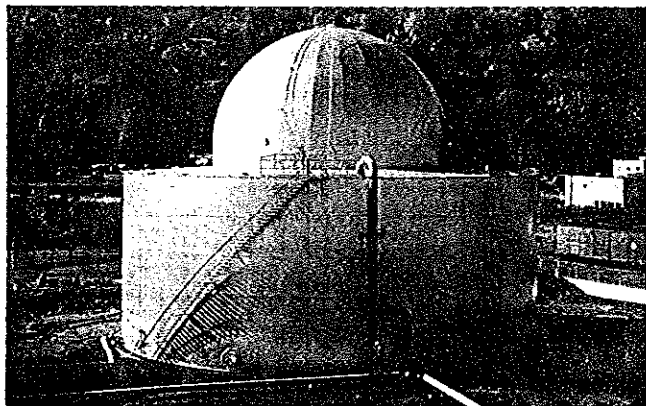


Figure 16—Tank with Vapor-Dome Roof

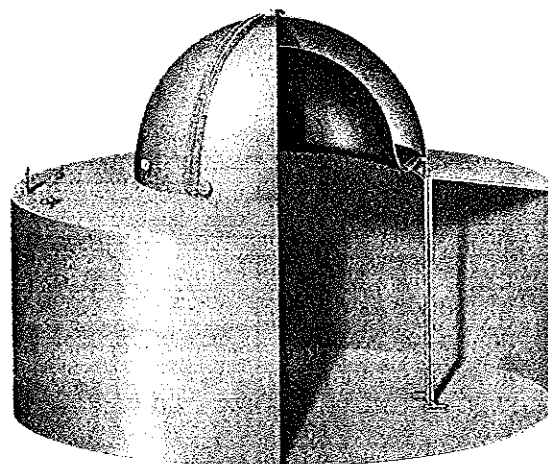


Figure 17—Cutaway View of Vapor-Dome Roof

### 13.1.3.2 Use of Tanks

Low-pressure storage tanks are used for the storage of the more highly volatile materials having a true vapor pressure at storage temperature exceeding the limits of API Standard 650, but not more than 15 pounds per square inch gage. Light crude oils, some gasoline blending stocks, light naphthas, pentane, and some volatile chemicals can be stored in low-pressure storage tanks.

Appendix R of Standard 620 provides for the storage of refrigerated products from 40 F to -60 F. Appendix Q provides for the storage of liquified hydrocarbon gases at temperatures not lower than -270 F. Both appendixes R and Q provide for single or double wall construction.

### 13.1.3.3 Types of Tanks

For pressures above about 5 pounds per square inch gage, the hemispheroidal, spheroidal, and noded spheroidal types of tanks are most commonly used for low-pressure storage tanks. All such tanks are designed to withstand the vapor pressure that may be developed within a tank having no devices or means to change the internal volume. As with atmospheric tanks, these tanks are provided with relief valves to prevent pressures from rising above safe values and are provided with other accessories.

Tanks which have cylindrical shells and cone or dome roofs are typically used for pressures less than about 5 pounds per square inch gage. Tank bottoms may be flat or have a shape similar to the roofs'. Hold-down anchorage of the shell is frequently required. Such tanks with a plain spherical roof and a noded spherical roof are shown in Figures 20 and 21, respectively; cross-sectional views are

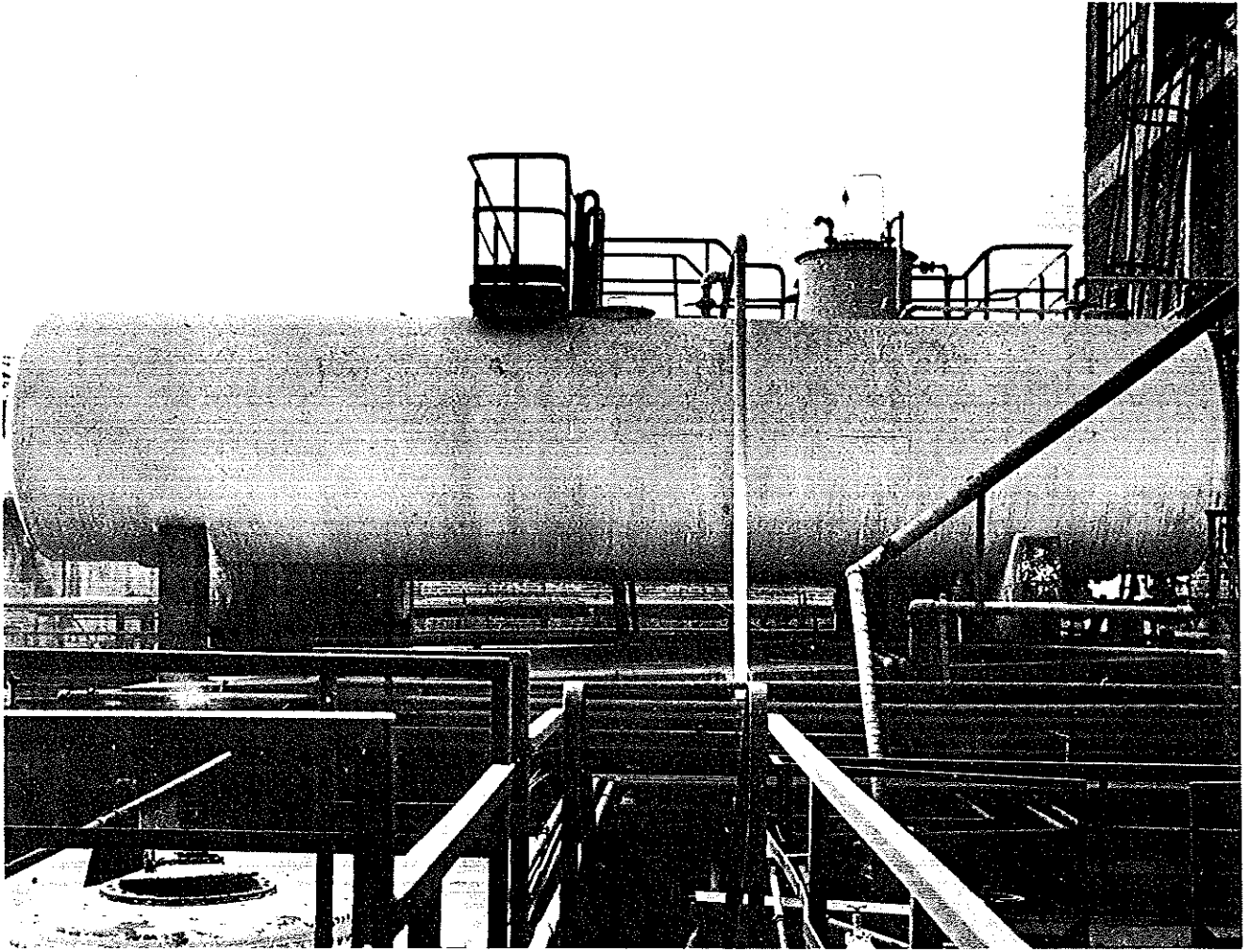


Figure 18—Horizontal Tank (Welded) Supported on Concrete Cradlers

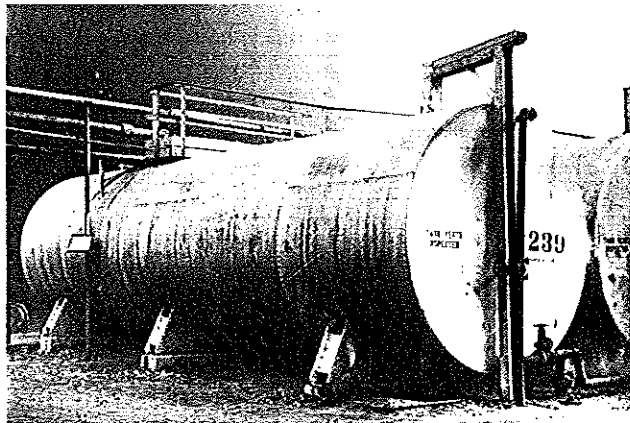


Figure 19—Horizontal Tank (Riveted) Supported on Steel Cradles

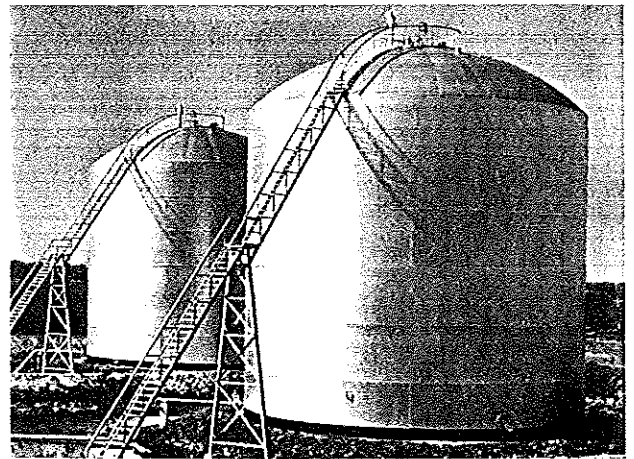


Figure 20—Plain Hemispheroids

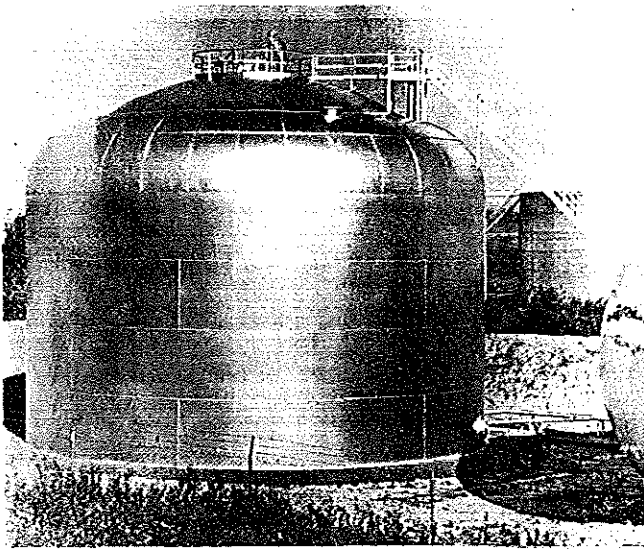


Figure 21—Noded Hemispheroid

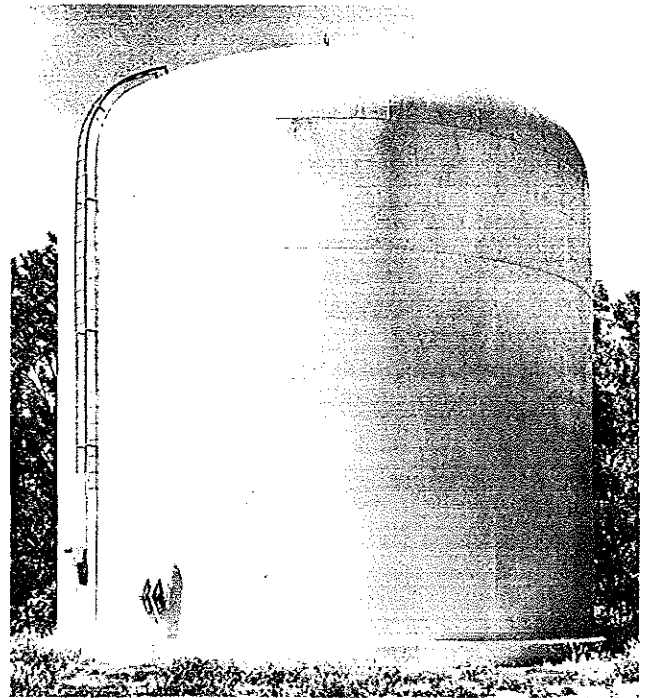


Figure 23—Plain Hemispheroid with Knuckle Radius

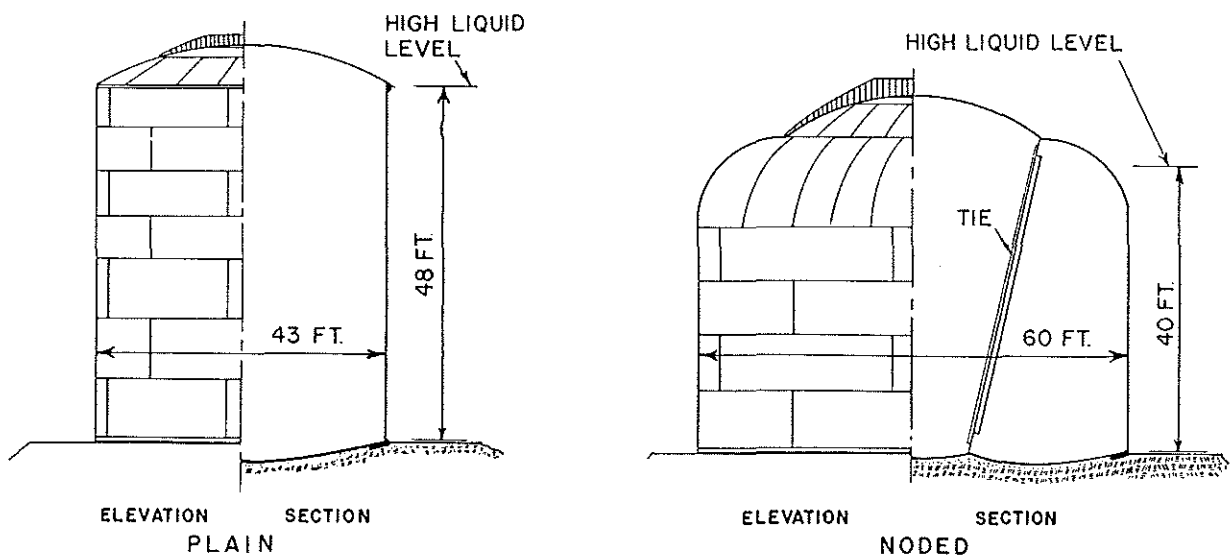


Figure 22—Drawings of Hemispheroids

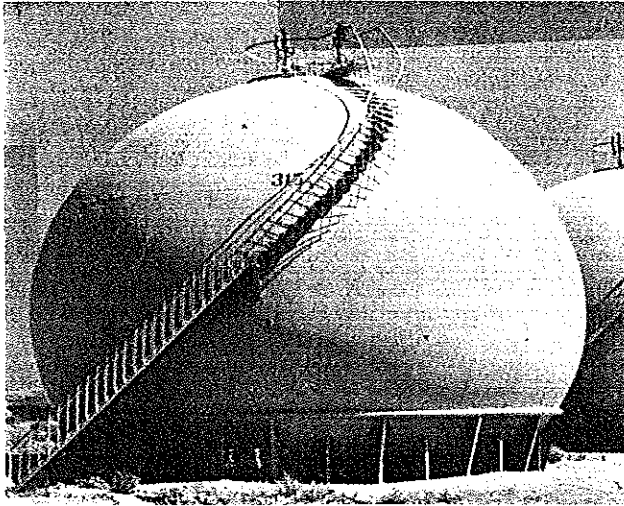


Figure 24—Plain Spheroidal Tank

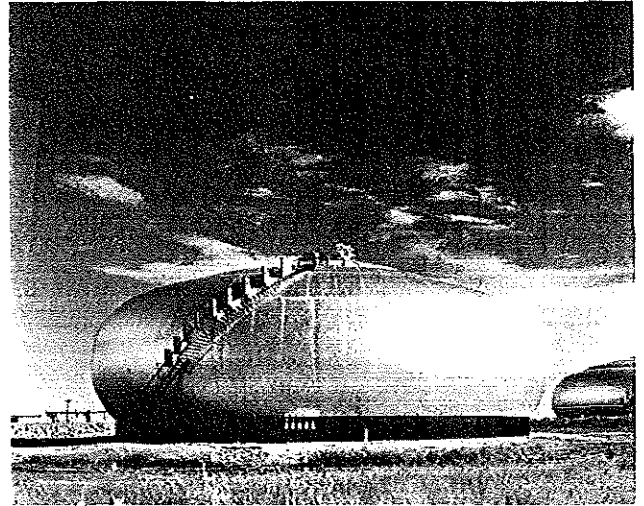


Figure 25—Noded Spheroidal Tank

shown in Figure 22. Figure 23 shows a spherical roof with a knuckle radius or smooth curves in the intersection of the shell and top head.

The spheroidal tank is essentially spherical in shape except that it is flattened, as shown in Figure 24. The noded spheroidal tank, shown in Figure 25, is used in the larger sizes and internal ties and supports are used to keep shell stresses low. Figure 26 shows a cross-section of a noded spheroidal tank.

## 13.2 Reasons for Inspection and Causes of Deterioration

### 13.2.1 GENERAL

Storage tanks are generally inspected to determine the physical condition of the tanks, the rate of deterioration, and, if possible, the causes of deterioration. With these factors known, proper measures can be taken to:

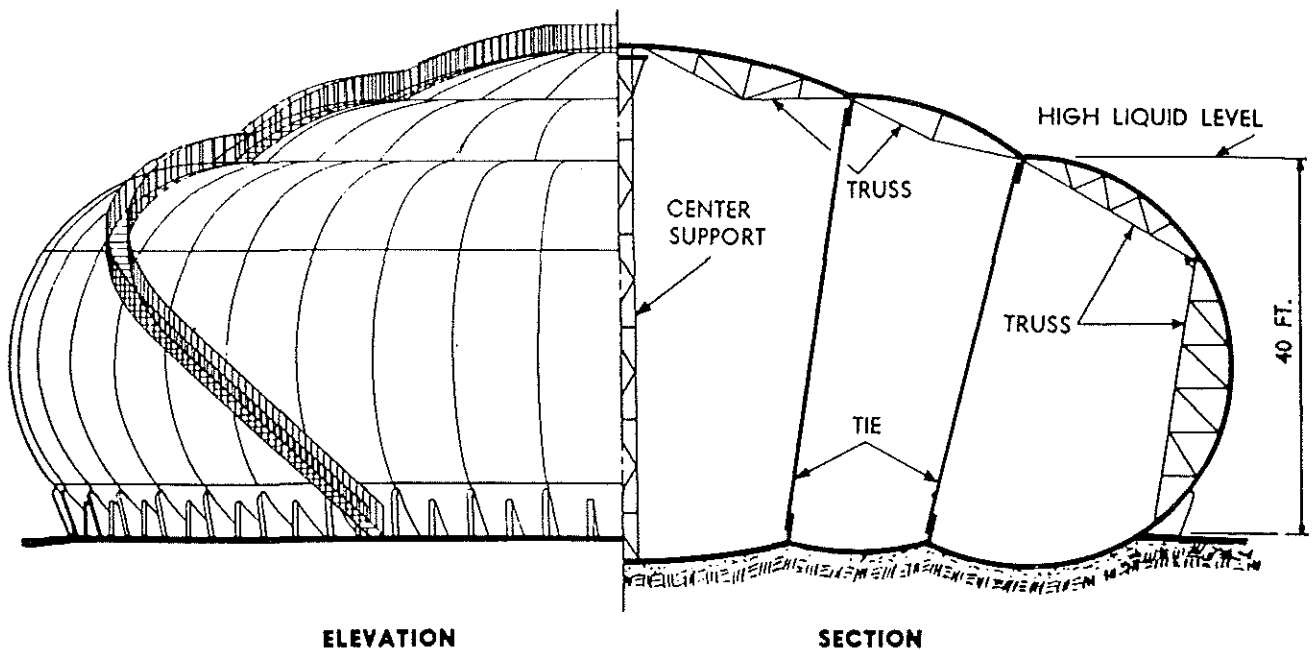


Figure 26—Drawing of Noded Spheroidal Tank

1. Reduce the probability of fire and the loss of storage capacity.
2. Maintain safe working conditions.
3. Make repairs or determine when repair or replacement of a tank may be necessary.
4. Prevent or retard further deterioration.
5. Keep ground water, nearby waterways, and the air free of hydrocarbon or chemical pollution.

### 13.2.2 CORROSION OF STEEL TANKS

Corrosion is the prime cause of the deterioration of steel storage tanks and accessories; therefore, finding and measuring the extent of corrosion is the major reason for inspecting tanks.

#### 13.2.2.1 External Corrosion

External corrosion of tank bottoms can be a serious problem. The material used for forming a pad under the bottom may contain chemical compounds that are corrosive. For example, cinders contain sulphur compounds that become very corrosive when moistened. The presence of clay as a contaminant in a sand pad will cause electrolytic corrosion, resulting in pitting at each point of clay concentration. Faulty pad preparation with poor drainage may allow water to remain in contact with the tank bottom. Underside corrosion can be reduced by topping the pad with asphalt. If a tank leaks corrosive material through the bottom, accumulation of the material can cause external corrosion of the tank bottom. For tanks that are supported above grade, as shown in Figure 27, improperly sealed foundation piers may allow moisture to accumulate between the tank and the supports and accelerate corrosion at such points.

The lower tank shell can become severely corroded externally, at or just above the grade line, when soil movement has raised the grade level covering the lower portion of the shell. External corrosion also occurs when external insulation wicks up ground water.

Atmospheric corrosion can occur on all external parts of a tank. This type of corrosion may range from negligible to severe, depending on the atmospheric conditions of the locality. A sulfurous or acidic atmosphere can destroy protective coatings and increase the rate of corrosion. External surfaces of the tank and its auxiliary equipment will corrode more rapidly if they are not protected with paint or other protective coatings or with cathodic protection. Any depressions or pockets in which water can lie for long periods will be points of concentrated corrosion.

The type of tank and the construction details used can affect the location and extent of external corrosion. Riv-

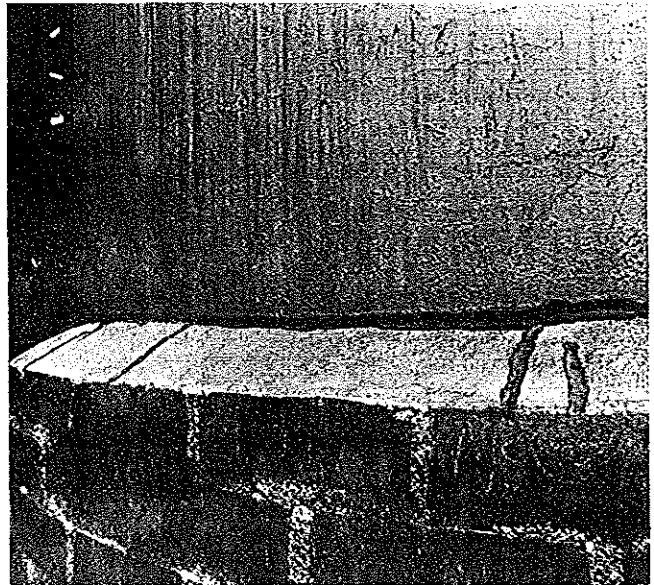


Figure 27—Foundation Seal

eted tanks offer many niches where acidic concentration cell corrosion can occur (see 13.4.2.9). Leaks at seams of riveted tanks can often destroy paint films around the leaks. External corrosion can then take place.

#### 13.2.2.2 Internal Corrosion

The occurrence of internal corrosion of storage tanks depends on the contents of the tanks and the material of which the tanks are constructed. The most severe corrosion occurs in tanks used for storing corrosive chemicals or petroleum products containing corrosive materials. In many cases it is necessary to use linings that are more resistant to the corrosion properties of the stored material than are the vessel materials. In some particularly severe services, it may be necessary to construct the tanks of a corrosion-resistant material.

Crude oil and petroleum products tanks are usually constructed of steel. Internal corrosion in the vapor space above the liquid of these tanks is most commonly caused by hydrogen sulfide vapor, water vapor, or oxygen, or any combination of the three. In the areas covered by the stored liquid, corrosion is most commonly caused by acid salts, hydrogen sulfide, or other sulfur compounds.

Other forms of internal attack, which may be considered as forms of corrosion, are electrolytic corrosion, hydrogen blistering, caustic embrittlement, graphitic corrosion of cast iron parts, and dezincification of brass parts. All these forms of attack, and corrosion in general, are described and explained in detail in Chapter II, "Conditions Causing Deterioration or Failures."

### 13.2.3 DETERIORATION OF NONSTEEL TANKS

Tanks can be constructed of materials other than steel. Both wooden and concrete tanks are sometimes used in refineries.

Tanks constructed of wood are subject to rotting unless they are covered with a protective coating. They also can be attacked by insects such as termites. Unless kept continually moist, these tanks can shrink and leak when refilled. The steel bands around them are subject to atmospheric corrosion.

Concrete tanks can be attacked by the contents, can crack because of settlement or temperature changes, or can spall because of atmospheric conditions and expose the reinforcement to atmospheric corrosion.

Tanks constructed of other materials, such as alloy steels or aluminum, are used for special purposes, and each one is a special problem. They are subject to the same mechanical damage as steel tanks. Other, nonmetallic tanks are also used, such as plastic, fiberglass, or glass

reinforced epoxy. These tanks also present special problems.

### 13.2.4 LEAKS, CRACKS, AND MECHANICAL DETERIORATION

Storage tanks should be inspected for leaks or incipient leaks in order to minimize or prevent economic loss, hazard to personnel, pollution of ground water and waterways, and damage to other equipment. The content of a refinery storage tank represents a considerable investment; therefore, loss of products through leaks should not be tolerated. Moreover, instantaneous failure and loss of the contents of a tank can result in extensive damage to equipment in the vicinity of the tank. Pollution of streams or waterways can result from such a failure when the tank is located near a waterway or is connected to one by a sewer. Figure 28 illustrates the complete loss of a tank from instantaneous failure. Proper inspection and maintenance



Figure 28—Damage from Instantaneous Failure

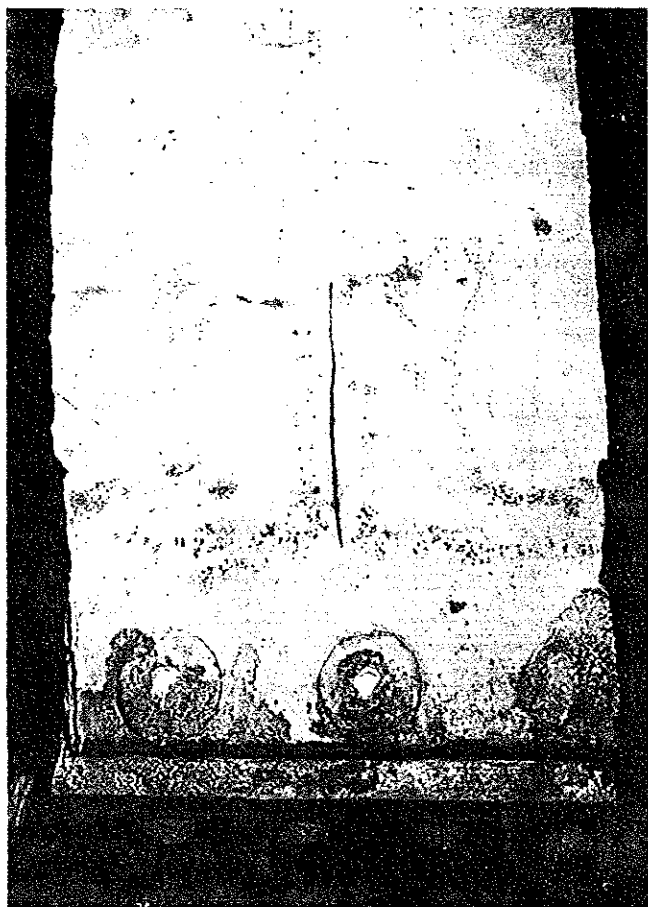


Figure 29—Cracks in Tank Shell Plate

minimize the probability of instantaneous failure. A detailed discussion of brittle failures can be found in Chapter II, "Conditions Causing Deterioration or Failures."

Leaks usually are caused by corrosion but can occur at improperly welded or riveted joints, at threaded or gasketed pipe connections or cover plates, or as a result of cracks in welds or in the tank steel.

Inspection of storage tank cone and floating roofs is important in order to prevent leakage of valuable product and air-contaminating vapors. This includes inspection of the floating roof seal.

Cracks can result from many causes, the most frequent being (1) faulty welding, (2) unrelieved stress concentrations around fittings, (3) insufficient reinforcement of openings, (4) stresses caused by settlement or earth movement, (5) vibration, and (6) poorly designed repairs. The most likely points of occurrence are at the bottom-to-shell connections, around nozzle connections and manholes, around rivet holes, at welded brackets, and at welded seams. The lower shell to skirt weld is especially critical because in relatively large or relatively hot tanks, it can act as a plastic hinge with the potential for cracking.

This potential can be suitably controlled by thickened, butt-welded, annular bottom rings, which are required by API Standard 650 for all of the higher design stress tanks and for the larger elevated temperature tanks. Photographs of cracks in tanks are shown in Figures 29, 30, and 31. In most cases, inspection should reveal a cracking condition before it becomes serious.

Many other types of mechanical deterioration can develop during the life of a storage tank. If such deterioration is discovered early enough by inspection, in many cases the continued deterioration can be halted and economic losses or failures prevented.

Tanks located in earthquake areas may suffer loss of product as a result of sloshing, damage to floating roofs, or collapse of cone roofs. For tanks having relatively large height to diameter ratios, buckling of the shell just above the bottom and cracking of the shell to bottom weld can occur. Where earthquake tremors occur, stresses in attachment nozzles (especially those connected to the tank bottom) can be quite high and can result in cracked nozzles. Similar damage can also occur to tanks subjected to high tides in hurricane areas.

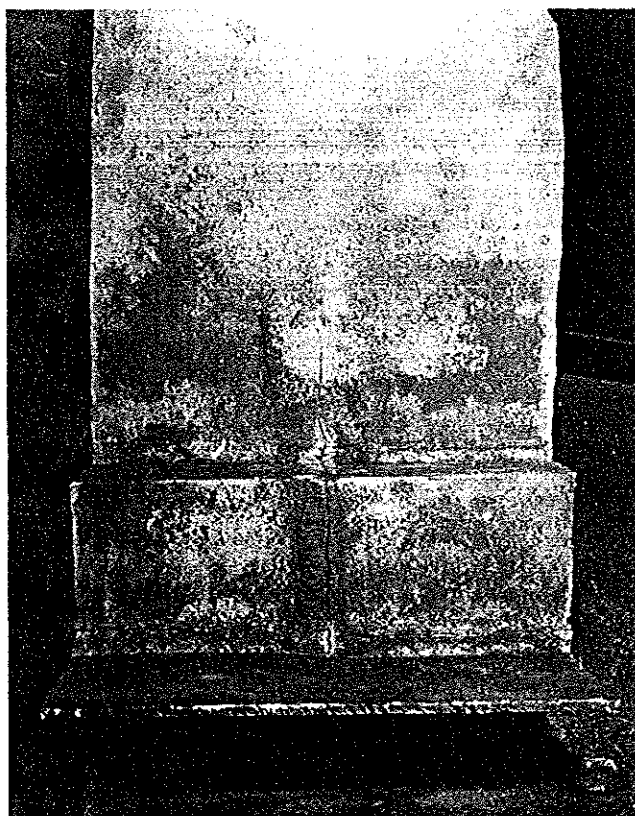


Figure 30—Cracks in Tanks at Butt weld of Inverted Angle Connecting Shell to Bottom

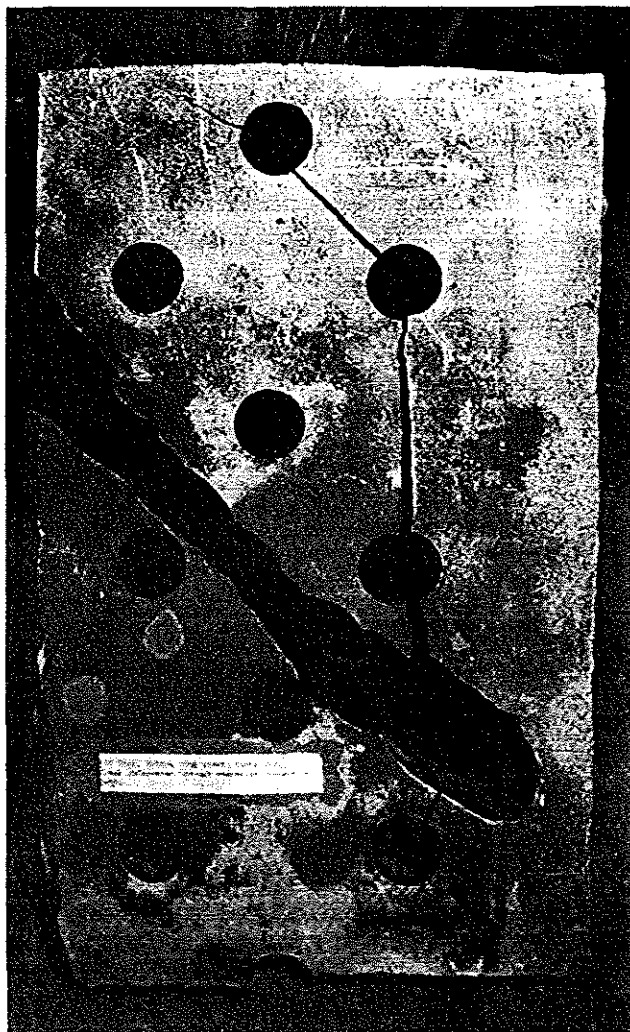


Figure 31—Cracks in Tank at Riveted Lap Joint to Tank Shell

Settlement of a tank caused by compression or movement of soil under the tank or tank foundation can also be considered a mechanical deterioration. Slight, even settlement of the whole tank normally would not cause damage nor be considered serious. More severe and uneven settlement would be cause for further investigation. Settlement can result from the frequent freezing and thawing of the ground, unusually high tides in tidal areas, or a slow flowing of the soil in marshy or swampy locations. Settlement may also occur at other locations. If settlement is to be controlled, especially for large tanks, it is of prime importance that a proper foundation be provided. A soil consultant survey would normally be required to ensure a proper foundation.

### 13.2.5 FAILURE OF AUXILIARY EQUIPMENT

Pressure of vacuum vents can fail to operate because of the presence of gummy or carbonaceous material, corrosion between moving parts and guides or seats, the deposit of foreign substances by birds or insects, the formation of ice, or tampering by unauthorized personnel. Examination of auxiliary equipment should be included in the periodic inspection interval schedule to ensure that proper operation and protection are maintained. This is discussed in more detail in Chapter XVI, "Pressure Relieving Devices."

Float leakage caused by corrosion or cracking, inoperative pulleys, tape breakage, or plugged guides can cause float-type gaging devices to be rendered inoperative. Remote and other types of gaging devices can become inoperative due to similar causes.

Equipment for draining water from floating roofs can be rendered inoperative due to plugging or mechanical damage caused by foreign material or ice. Drain piping or hoses can develop leaks that will allow tank contents to leak from the drain or water to flow into the tank. Plugged or leaking drains can accumulate enough water to sink a pan- or pontoon-type floating roof.

Deterioration of auxiliary mechanical equipment, such as ladders, stairways, and platforms can occur from corrosion, wind, and other external forces. Because of the direct human safety aspects involved, the reasons for inspection are obvious.

### 13.3 Frequency and Time of Inspection

Inspection intervals for storage tanks are determined by the following factors:

1. The nature of the materials stored.
2. The results of visual maintenance checks.
3. The availability of the equipment.
4. Corrosion allowances and corrosion rates.
5. Conditions at previous inspections.
6. The methods and materials of construction and repair.
7. The location of tanks, such as those in isolated or high-risk areas.
8. The potential risk of air or water pollution.
9. Jurisdictional requirements.

The interval between complete inspections of a tank—both internal and external—should be determined by its service history unless special reasons indicate that an earlier inspection must be made. For tanks in mild corrosive service, infrequent inspections may be adequate. For tanks in highly corrosive service, inspections at shorter intervals may be necessary. A fairly complete, continuing history of the service of a tank should be available so that complete inspections can be scheduled with a frequency proportional

to the corrosion rate of the tank. When in-service, nondestructive methods of inspection are used, a tank's in-service period may be extended.

Jurisdictional regulations, generally at the state level, are becoming increasingly numerous and restrictive. These regulations include vapor loss requirements, seal condition, leakage, proper diking, and repair procedures. Knowledge of such regional regulations is necessary to ensure compliance with scheduling and inspection requirements.

A tank's exterior should be visually inspected more frequently than complete inspections are made since such an inspection can be made without removing a tank from service. These partial inspections should include checking for corrosion, leaks, settlement, and improper functioning of the more susceptible external mechanical equipment, such as vents, pressure vacuum valves, gaging devices, and water-draining equipment. Water drains on floating roofs should be inspected after a rainfall.

Malfunctions of external mechanical equipment can usually be corrected while the tank is in service. If leakage is noted during a partial inspection, it should be determined whether the leakage is caused by a crack, internal or external corrosion, or some condition that can be corrected without removing the tank from service. If the condition appears serious, a more complete inspection—internal or external, or both—is indicated as soon as possible.

Internal inspections should coincide with the removal of tanks from service for cleaning to avoid the labor and expense of removing a tank from service and cleaning it solely for inspection purposes.

New tanks should be inspected within a reasonable period of time if previous experience with the stored stock is not available. The interval before the first inspection will depend on the service. For highly corrosive chemicals, a 6-month period might be desirable; whereas for finished lubricating oil service, a period longer than 10 years might be considered reasonable. Intermediate intervals may be selected for other services, depending on the corrosiveness of the material. Generally, the heavier, more viscous oils form a protective coating that retards corrosion. The interval between subsequent inspections may be adjusted in accordance with the corrosion rates determined from previous inspections.

## 13.4 Methods of Inspection and Limits

### 13.4.1 PREPARATION FOR INSPECTIONS

Before entering or reentering any tank, certain precautions are necessary. The procedures used in making a tank safe for various types of work are discussed in Chapter V, "Preparation of Equipment for Safe Entry and Work."

Briefly, the tank must be freed of gas and any residues that might generate gas. Precautions should be taken when pyrophoric iron sulfide or residues of leaded gasoline are present, as explained in Chapter V.

Inspection may proceed after the tank has been certified to be free of gas, is clear of gas-generating residues and toxic materials, is isolated from any source of toxic or gas-generating materials, and has an atmosphere containing sufficient oxygen.

It is advisable to make a visual inspection of overhead parts and all supports before entering a tank to ensure that there are no loose purlins, large patches of loose scale, weakened support columns or brackets, or any other object that might fall and cause personal injury.

Prior to the inspection all tools and equipment needed for tank inspection and personnel safety should be checked for availability and proper working condition (see Chapter V). Safety signs, as needed, should also be provided.

Tools which may be used in inspection work are discussed in Chapter IV, "Inspection Tools." Specifically, the tools listed in item 1 should be in readiness for almost all tank inspections, and those in item 2 should be quickly available.

#### 1. Tools for tank inspection.

Pit gage  
Drill and drill bits  
Hook gage  
Inside calipers  
Inspector's hammer  
Knife  
Notebook  
Outside calipers  
Paint or crayon  
Permanent magnet  
Pipe tap, 3/8-inch internal pipe size  
Plumb bob and line  
Portable lights  
Special pipe plugs, 3/8-inch internal pipe size  
Square  
Steel rule  
Straightedge  
Thin-bladed scraper  
Ultrasonic thickness indicators  
Wrench

#### 2. Tools available if necessary.

Carpenter's or plumber's level  
Magnetic-particle inspection equipment  
"Megger" ground tester  
Dye-penetrant inspection equipment  
Radiographic equipment  
Respiratory equipment  
Sandblasting equipment  
Surveyor's level  
Trepanning saw  
Vacuum box tester  
Vacuum pump

Other equipment that may be required for inspection includes planking, cribbing timbers, scaffolding, bosun's chairs, and ladders. External scaffolding may be erected before inspection begins. Special tank scaffolding that is

mounted on wheels may be useful for inspection and repair purposes.

It is desirable to have the following equipment and services available.

1. Steam, water, or compressed air for removing gases from the tank.
2. Water for tank washing and testing.
3. Compressed air for operating tools.
4. Fresh air masks.
5. Electric power for tools and lights.

However, in isolated locations some of these services may not be available, and substitute methods may have to be employed. This is especially true for equipment required for gas-freeing, which may have to be done by natural ventilation. In addition, soap solution may be required for testing. If pressure tests are to be made, a pressure gage will be required.

As a last and very important point in preparing for inspection, all persons working in the area, or any who may enter the area, should be informed that personnel will be working in the tank. Posting safety signs outside the tank is a good precaution. Personnel working inside the tank should also be kept informed when any work on the exterior of the tank—particularly the roof—is to be done.

### 13.4.2 EXTERNAL INSPECTION—TANK IN SERVICE

Generally, as indicated in 13.3, much of the external inspection can and should be made while a tank is in service to minimize the length of time the tank will be out of service.

#### 13.4.2.1 Ladders and Stairways

External inspection should start with any ladders or stairways on a tank. These should be examined carefully for corroded or broken parts. The condition of ladder or stairway parts may be checked by looking carefully, tapping, or picking at the part to determine whether these parts will be safe for use—at least until the next inspection.

On large tanks, stairways may have intermediate supports, as shown in Figure 32. When concrete pedestals are used for such supports, they should be checked for cracks, spalling, or more serious defects before starting an inspection of the stairway itself. A scraper will aid in determining the extent of any concrete deterioration. Bolts set in the concrete should be examined carefully for corrosion at the point of contact. A rapid form of crevice corrosion can take place at this point.

Ladder and stair treads should be checked for wear and corrosion. In addition to loss of strength caused by such loss of metal, the tread becomes slippery when the surface

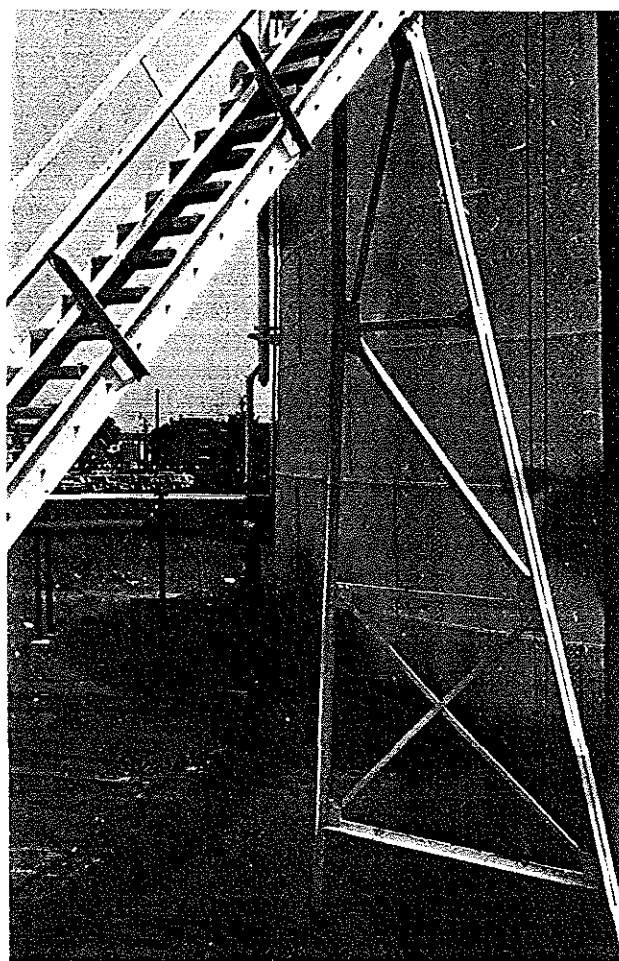


Figure 32—Stairway Intermediate Support

is worn smooth. Bolts and rivets should be checked for looseness, breakage, and excessive corrosion. Welded joints should be checked for cracks. Handrails may be shaken to give an indication of their condition. Particular attention should be given to tubular handrails, which may have corroded from the inside. Crevices where water can collect should be closely checked by picking at them with a scraper or knife and by tapping them with a hammer. Such crevices exist at bracket connections, around bolts and nuts, and between stair treads and support angles. If the surfaces are painted, corrosion may exist under the paint film. Rust stains visible through the paint or a general lifting of paint in an area are evidences of such corrosion.

#### 13.4.2.2 Platforms and Walkways

Platforms and elevated walkways can be inspected in the same manner as ladders and stairways. Flooring thickness can be checked with calipers at the edges and by tapping with a hammer in other areas. Low spots where water can

collect should be checked carefully because corrosion may be rapid in such areas. A small drain hole should be drilled in the area to prevent future accumulation of water. Platform supports should also be measured to determine thickness and should be checked for buckling or other signs of failure.

All defects found, which do not require immediate repair before inspection can proceed, can be marked with paint or crayon and recorded in a field notebook. This will save considerable time by avoiding backtracking.

### 13.4.2.3 Foundations

The foundations of tanks may be made of clay pads, elaborate steel and concrete piers, rings, or pads. Clay pads can be visually checked for washing out and for uneven settlement. All types of foundations should be checked for settlement by using a surveyor's level to check the amount of settlement. If uneven or excessive settlement is noted, the situation should be corrected before serious damage occurs. Records of settlement should be maintained for tanks that are known to be settling. Concrete pads, base rings, and piers should be checked for spalling, cracks, and general deterioration. Scraping of suspected areas usually will uncover such deterioration. Figure 33 shows an example of a base-ring failure.

The opening or joint between a tank bottom and the concrete pad or base ring should be sealed to prevent water

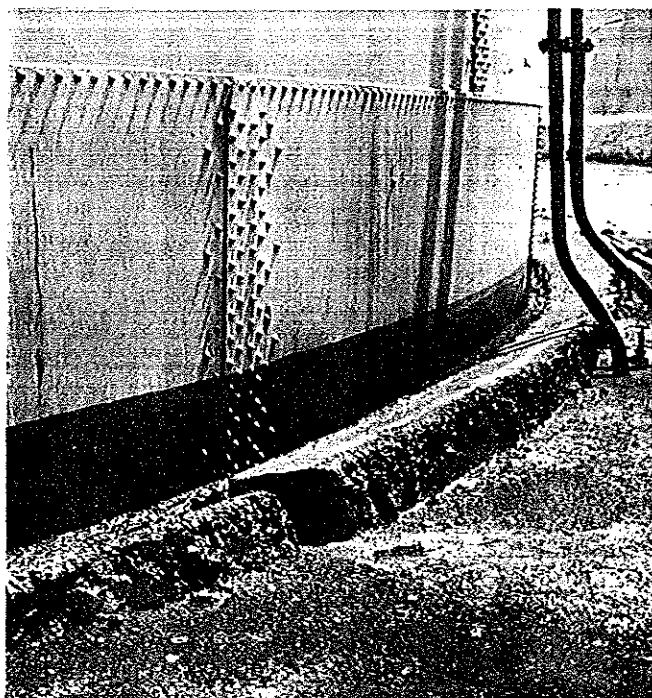


Figure 33—Failure of Concrete Base Ring

from flowing under the tank bottom. A visual inspection combined with some picking and scraping will disclose the condition of this seal.

Any wooden supports for small tanks, stairways, or other accessories can be checked for rot by striking them with a hammer or by picking at them with a scraper. Any steel columns or piers can be hammered or measured with calipers to check for corrosion. Caliper readings can be checked against the original thickness or against the thickness of obviously uncorroded sections to determine any loss of metal. Piers or columns should be examined to see if they are plumb. Usually, this operation may be done visually; however, plumb lines and levels can be used if more accuracy is desired.

### 13.4.2.4 Anchor Bolts

The condition of anchor bolts can usually be determined by visual inspection. A hammer blow to the side of the nut may reveal complete corroding-away of the anchor bolt below the baseplate, as shown in Figure 34. Distortion of anchor bolts, buckling of columns, and excessive cracking of concrete are indications of serious foundation settlement.

### 13.4.2.5 Pipe Connections

All pipe connections to a tank should be inspected for external corrosion. Visual inspection combined with scraping and picking will reveal the extent of this condition. If piping enters the ground, the soil around the pipe should be dug away, as soil corrosion may be especially severe at such points. After the pipe is exposed, it should be thoroughly scraped and cleaned to permit visual inspection.

Connected piping should be inspected for possible distortion if a tank has settled excessively, especially if the tank has been subjected to earthquake or high tides. In this event, water drawoff and cleanout nozzles connected to the

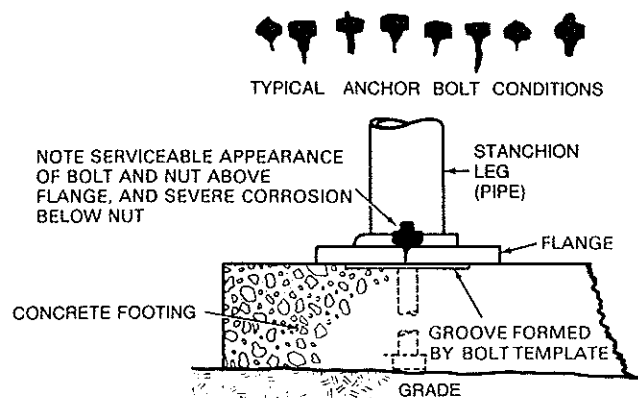


Figure 34—Corrosion of Anchor Bolts

bottom may have been subjected to severe shearing stresses. Therefore, special attention should be given to such nozzles. Internal explosions, hurricane winds, and fires can also cause distortion. If there is any evidence of distortion or cracks around nozzle connections, all seams and the shell in this area should be examined for cracks. The area should preferably be sandblasted or wire-brush cleaned to the base metal. Magnetic-particle or dye penetrant techniques may be used to supplement visual examination.

#### 13.4.2.6 Ground Connections

Some tanks are provided with ground connections. The ground connections should be visually checked for corrosion at the point where they enter the earth and at the mechanical connection to the tank. If any doubt exists about the condition of the ground, its resistance can be checked. The total resistance from tank to earth should not exceed approximately 25 ohms. The measurement of the resistance to the absolute earth is quite difficult, and all results are approximations of varying degrees of accuracy.

#### 13.4.2.7 Protective Coatings

The condition of the protective coating on a tank should be determined. Rust spots, blisters, and film lifting are the types of paint failure usually found. Rust spots and blisters are easily found by visual inspection. Film lifting is not easily seen unless the film has bulged appreciably or broken. It can be found by picking at the film with a thin-bladed scraper or knife in the suspected area.

Paint blisters occur most often on the roof and on the side of the tank receiving the most sunlight. Film lifting commonly occurs below seam leaks. Other points at which the paint may fail are in crevices or depressions and at tank seams which are welded, riveted, or bolted. The portion of the tank wall behind liquid-level gage boards is often overlooked and thus may be the location of deterioration. The paint on the tank roof is especially susceptible to rapid failure. In particular, the paint on floating-type roofs should be inspected carefully. Such roofs cannot be safely painted except when the tank is out of service or when the roof is in the high position and inactive.

#### 13.4.2.8 Insulation

If a tank is insulated, the insulation should be examined. A visual examination is normally sufficient. Careful inspection should be made around all nozzles and around the saddles of horizontal tanks. A few samples may also be removed—especially on the shaded side of the tank—to better determine the condition of the insulation and the metal walls of the tank under the insulation. Insulation-supporting clips, angles, bands, wires, and the like should

be spot-checked for corrosion and breakage. Corrosion can occur beneath polyurethane insulation, particularly in the areas of the lower shell where the insulation may be in contact with surface water. This area should be checked carefully.

#### 13.4.2.9 Tank Walls

In the previous paragraphs, emphasis has been placed on inspection for paint failures, which is important; however, locating corrosion on the external surfaces of the tank (at the points of paint failure, under insulation, behind gage boards, inside valve boxes, at points that have not been painted, and on unpainted tanks) is of even more vital importance. Although most commonly caused by moisture, oxygen, sulfur, and acids in the surrounding atmosphere, external corrosion may also occur on the underside of tank bottoms from corrosive elements in the soil, on the shell near the bottom from soil or other foreign matter with which the shell may be in contact, and at points of tank leakage if the tank contains corrosive materials.

If any foreign material has collected around the bottom of the shell, or if the tank has settled or was originally below grade, a close inspection should be made at and below the grade line. The shell should be uncovered completely if possible; if not, it should be uncovered for at least a foot below grade at several points. Accelerated corrosion often occurs at the grade line, as shown in Figure 35.

The external surfaces of the shell, particularly at leaks and under insulation, should be checked visually, supplemented by picking, scraping, and hammering, to locate corroded areas. When evidence of extensive external corrosion or other types of deterioration warrant, it may be necessary to erect scaffolding around the tank for access to all surfaces. Alternately, a bosun's chair, portable ladders, or cranes can be used.

Any evidence of corrosion should be investigated. Corrosion products or rust scale can be removed by picking, scraping, or wire brushing so that the depth and extent of the corrosion may be determined. Vigorous rapping with a hammer, or an air-driven chipping hammer with a blunt chisel, will pop hard, thick rust scale off the tank rather quickly and efficiently. However, the hazards of such methods should be evaluated beforehand.

If corrosion is found, thickness measurements may be taken at the most corroded points. Normally, one measurement should be made on each shell ring. However, if much corrosion is evident, it may be desirable to take several measurements on each ring. Ultrasonic instruments are generally used for obtaining these measurements. When the tank is out of service, test drillings may be desirable to verify the instrument measurements. The depth of localized corroded areas can be measured by placing a straight-edge, long enough to span the corroded area, on the longi-

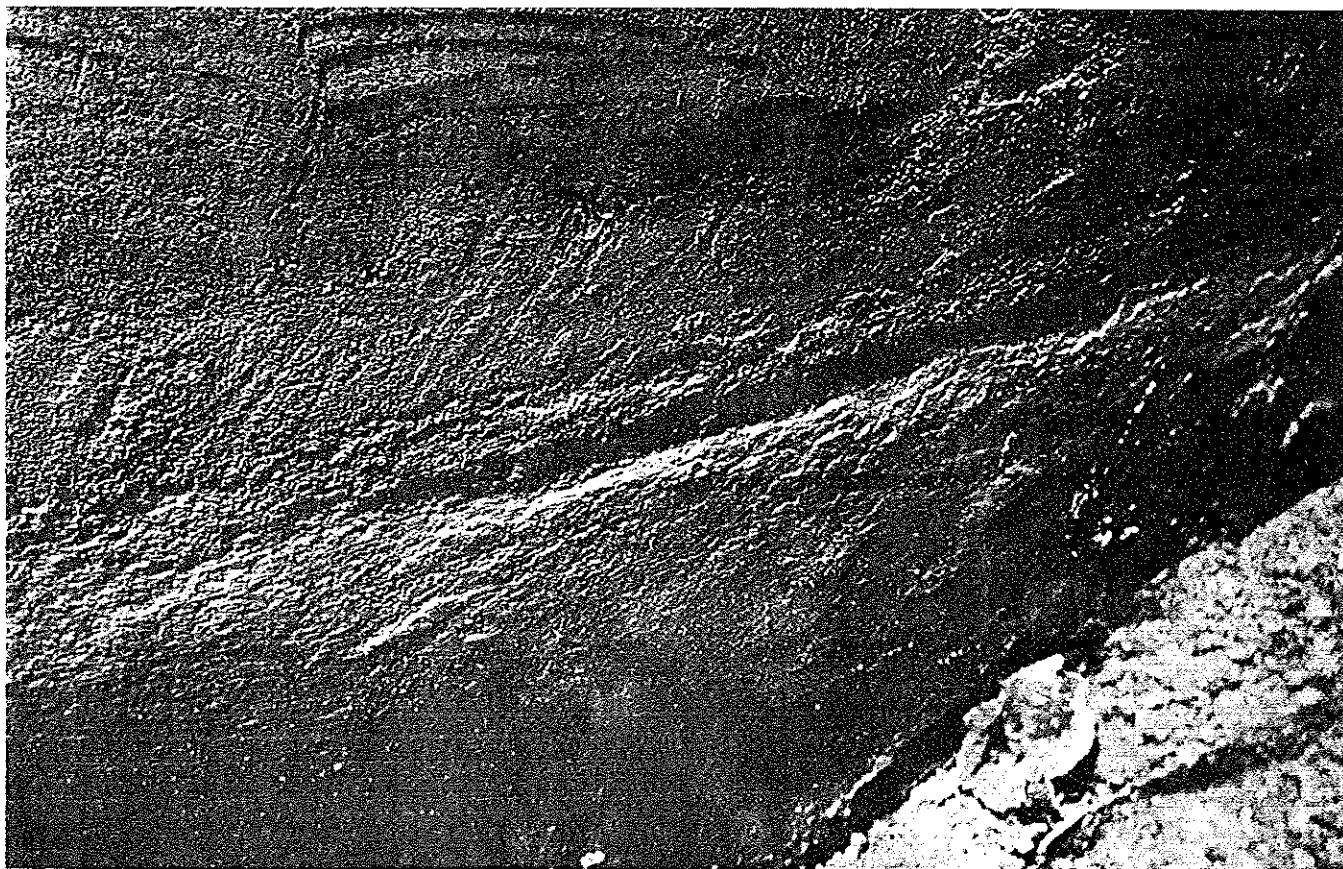


Figure 35—Shell Corrosion (External) at Grade

tudinal axis and measuring from the axis to the lowest point of the corroded area. The depth of pits can be measured by a pit gage. Sun, shade, and prevailing winds affect the rate of corrosion. These factors should be considered when deciding on the number and location of measurements to be taken. Ultrasonic instruments are the most practical means of measuring corrosion. The test-drilling method may be used if no ultrasonic instruments are available. Shells of tanks can be inspected ultrasonically from ground level by the use of a sectional pole. Attached to the end of the top section of the pole is a magnetic holder for the instrument transducer. Mechanical crawler devices are also available to permit tank shell thicknesses to be obtained from ground level. In any event, the thickness measurements taken from the outside should be compared with thickness measurements that may subsequently be taken from the inside so that the thinnest points will be known. In obtaining shell thicknesses, special attention should be given to the upper 24 inches of uncoated shells of floating roof tanks. These portions of the shell plates commonly corrode at a higher rate than the lower shell plates because of constant exposure to the atmosphere.

The outside stiffeners and wind girders of a tank can be inspected visually and by hammer testing. Thickness measurements should be made at points where corrosion is evident. Under normal conditions, with little corrosion evident, one measurement should be sufficient. Outside calipers and a steel rule are usually adequate to take these measurements, although ultrasonic instruments may be used where calipers cannot be applied. Any pockets or crevices between the rings or girders and the shell should receive close attention. If the stiffening members are welded to the shell, the weld seams should be visually checked for cracks. If any evidence of cracking is found, the seams should be cleaned thoroughly by wire brushing or sandblasting and checked by the magnet-particle or dye penetrant method. If the magnetic-particle method is used for detecting cracks while the tank is in service, magnets, rather than direct-current flow that would produce electrical sparks, should be used for energizing the field.

If caustic is stored in a tank, the tank should be checked for evidence of damage from caustic embrittlement. The most probable place for this to occur is around connections for internal heating units or coils. This type of deterioration is manifest by cracks that start on the inside of the

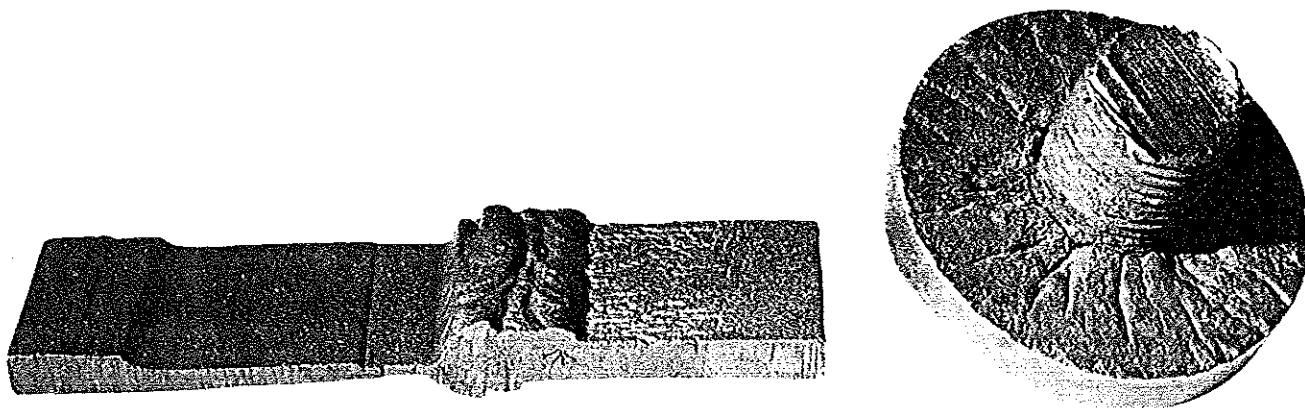


Figure 36—Caustic-Embrittlement Cracks

tank and progress through to the outside. If such a condition exists, the caustic material seeping through the cracks will deposit readily visible salts (usually white). Figure 36 shows an example of caustic embrittlement.

The shell and, to the extent possible, the bottom of the tank should be checked for hydrogen blisters. This form of deterioration is discussed further in Chapter II. Figure 37 and 38 show the general appearance of blisters that can occur either on the inside or outside surfaces. They are found most easily by visual examination and by touch. Many small blisters can be found by running fingers over the metal surface. The location of large blisters should be recorded so that when the tank is out of service, further inspection of the area can be made.

In addition to an examination for corrosion, the shell of the tank should be examined for leaks, cracks, buckles, and bulges.

Leaks are often marked by a discoloration or the absence of paint in the area below the leaks. Leaks are sometimes found by testing the tank, as discussed in 13.4.5, or by other methods discussed in 13.4.5.6. The nature of any leaks found should be carefully determined. If there are any indications that a leak is through a crack, the tank should be removed from service as soon as possible, and a complete inspection with subsequent repairs should be made.

Cracks will most commonly be found at the connections of nozzles to the tank, in welded seams, in the metal ligament between rivets or bolts, between a rivet or bolt and the edge of the plate, at connections of brackets or other attachments to the tank, and at the connection of the shell to the bottom of a welded tank. When an angle is used at the bottom joint of a welded tank, cracking may occur in the shell plate. Usually, close visual inspection is all that is required when checking for cracks. However, if any signs of cracking do exist, the entire suspected area should be

sandblasted and the magnetic-particle or dye penetrant method used. If the magnetic-particle method is used while the tank is in service, magnets, rather than direct-current flow, should be used for energizing the field.

Buckles and bulges will normally be readily evident by visual inspection, even from a distance. Inspectors should consider that there is always a slight distortion in the vicinity of a welded seam and that other small distortions may be found. Distortions can be measured by placing a straightedge lengthwise against the shell. It is important to determine the cause of distortion. Distortion can be caused by settlement of the tank, wind, earthquake, internal pressure in the tank caused by defective vents or relief valves, a vacuum in the tank, very severe corrosion of the shell, movement of connected piping, or other mechanical damage. Figure 39 shows an extreme case of tank buckling caused by inadequate vacuum venting.

When a tank is of welded construction and has serious distortions, the welded seams may be severely overstressed at some points and may tend to crack. As indicated previously, the joints most susceptible to cracking are those at connections, at the bottom-to-shell joint, and at the vertical shell seams. When cracking is suspected, the magnetic-particle method of inspection is one of the most suitable. In using this method, the seams to be inspected should be sandblasted or wire-brushed clean; if the welded surface is rough or extends materially above the surface of the joined plates, it may be necessary to grind the welds to obtain a reasonably smooth surface without sharp corners or discontinuities. Grinding should not be done while the tank is in service. The dye penetrant method can also be used to find cracks. If the magnetic-particle method is used while the tank is in service, magnets, rather than direct-current flow, should be used for energizing the field. The radiographic inspection method can be used, but this method requires that the tank be emptied and prepared for entering.

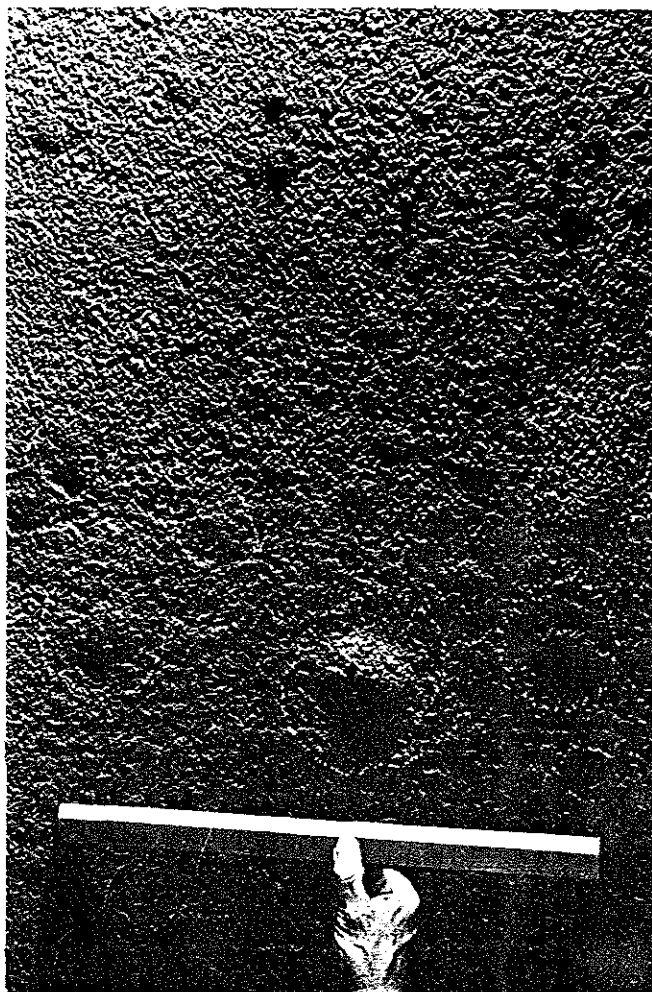


Figure 37—Small Hydrogen Blisters on Interior of Shell of Tank

If the tank is of riveted or bolted construction, a number of rivets or bolts, selected at random, should be checked for tightness. This may be done by lightly rapping the rivet or bolt head sidewise with a hammer or wrench while holding a finger against the opposite side and in contact with the plate. Movement of the rivet or bolt will be detected easily. In the Gulf Coast and other coastal areas, bolts or rivets tested in this manner will need to have the paint touched up after tapping. In such areas it may be advisable to defer this test until the tank is out of service and the tapping can be done on the inside of the tank.

#### 13.4.2.10 Tank Roofs

The roof or top head of a tank can be inspected by thorough hammering. A safety belt should be used when working on old roofs which are suspected of being thin. On a fixed-type roof, planks long enough to span at least two roof rafters should be laid and used as walkways, at least

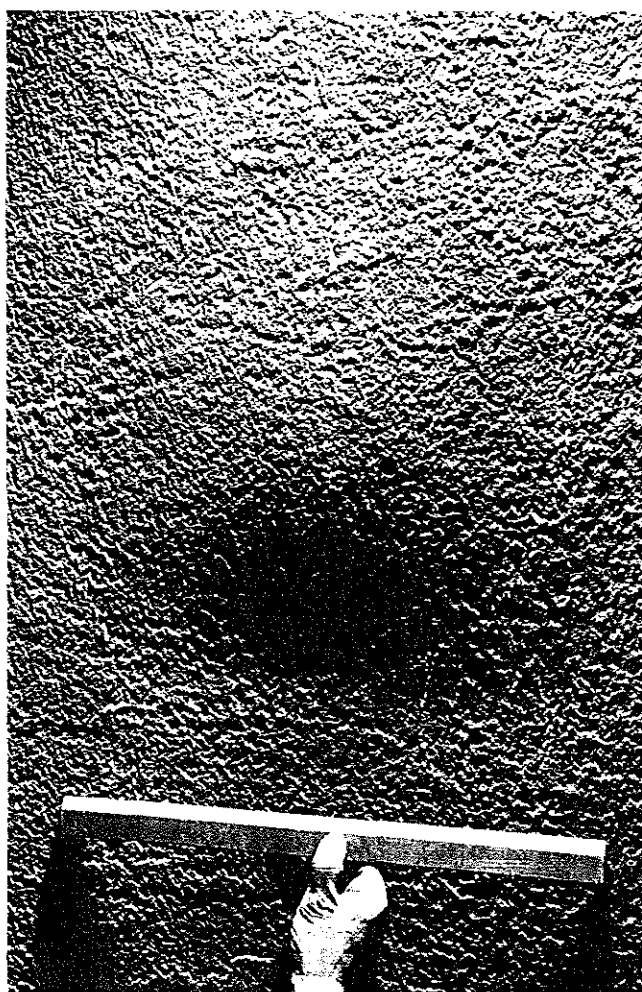


Figure 38—Large Hydrogen Blister on Interior of Shell of Tank

until the safety of the roof is determined. On a floating roof, the same precautions should be taken. In addition, because of the possible existence of harmful vapors, the roof should be in the high position if volatile liquid is in the tank. If the roof is not in the high position, a gas test should be made before personnel without respiratory equipment are allowed on the roof. It may be desirable to station a second employee with respiratory equipment on the platform to give assistance if necessary.

Leaks in a floating roof may be found while the tank is in service, but not without the use of vapor tests and other recommended safe practices. Inspection should be visual and should be performed as quickly as possible, especially if an entrance must be made to the lower deck of a pontoon-type or double-deck floating roof.

The tracks, rollers, and ladders of any rolling ladders on the roof of a floating-roof tank are subject to wear and distortion. The ladder can be checked in the same manner as outside ladders or stairs. If the ladder has come off the

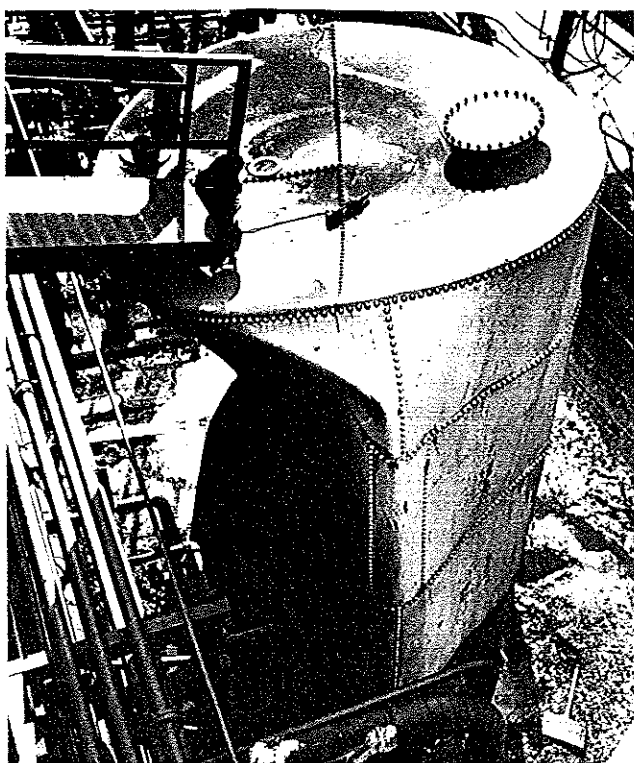


Figure 39—Tank Failure Caused by Inadequate Vacuum Venting

tracks as a result of roof rotation, the roof and especially the roof seals should be examined visually for physical damage. The rollers on the ladder base should be free.

Leaks at seals of floating roofs may be more difficult to find visually, but they are also less important than other leaks. Some leakage will almost always occur; however, excessive leakage indicates malfunctioning of the seals. Visual inspection will usually make this evident, and corrections generally can be made while the tank is in service. If permanent repairs cannot be made, the leak or any temporary repairs should be noted in the records so that permanent repairs can then be made when the tank is removed from service.

Water drains on floating roofs should be inspected frequently for breakage or blockage. If blocked, an accumulation of liquid can cause pan- or pontoon-type roofs to sink.

In addition to the pertinent inspections performed on floating roofs and cone roofs, the seals around columns and the ladder of covered floating roofs must be checked for leakage and workability. The ladder and columns should be checked for plumbness.

Platforms and guardrails on a roof may be checked carefully in the same manner as that described for such equipment on the sides of a tank.

External corrosion on roof surfaces will usually be most severe at depressions where water can remain until it evaporates. When corrosive vapors in a tank leak through holes in the roof, pressure vents, floating-roof seals, or anywhere, serious external corrosion may occur in the area of the openings. Inspection for corrosion on the external surfaces of a roof may follow the same procedure as for the shell and can be done more easily. Thickness measurements of apparently badly corroded areas can be taken by means of ultrasonic instruments.

#### 13.4.2.11 Auxiliary Equipment

Flame arresters should be opened at intervals determined by experience for each locality, and the screens or grids should be visually inspected for cleanliness and corrosion. Bees and mud daubers occasionally plug arresters. The venting capacity is thereby seriously reduced under either pressure or vacuum conditions, thus increasing the possibility of tank failure. In the event of an explosion in tanks having a connected gas-collecting system, flame arresters should be checked immediately for signs of damage.

Earthen dikes should be inspected to ensure that they are not eroded and are maintained at the desired height and width.

Masonry firewalls should be checked for cracks, erosion, or any other signs of deterioration.

Stairways or walkways over dikes or firewalls should be inspected in the same manner as those on a storage tank.

Drains for firewall enclosures and dikes should be inspected to ensure that they are not plugged and that they are equipped with an operable control device.

Foam lines, chambers, and connections; steam smothering lines (if used); and other fire fighting equipment attached to or installed on storage tanks should be carefully inspected visually. The parts can be hammer-tested or thickness measurements can be taken when deterioration is indicated.

Any other auxiliary equipment should be inspected to ensure that it is in an operable and safe condition.

Tank relief valves and pressure and vacuum vents are discussed in Chapter XVI.

### 13.4.3 External Inspection—Tank Out of Service

#### 13.4.3.1 Tank Bottoms

Corrosion on the underside of tank bottoms that rest on pads or on the soil cannot be inspected readily from the outside. However, when it is necessary to do so, a tunneling method may be used when the tank is empty. As it is

difficult to refill a tunnel properly, this method should be applied only to locations near the edge of the tank. Clean sand or crushed limestone are the best types of fill material. The coupon-removal method, discussed in 13.4.4.4, is safer and usually quicker.

### 13.4.3.2 Pipe Connections

The thickness of all steel pipe connections should be checked by using ultrasonic instruments or by hammer testing. (Cast iron pipe or nozzles should not be hammer tested.) Visual inspection accompanied by scraping and picking will normally be sufficient to reveal external corrosion. Soil corrosion may be especially severe on pipes that enter the ground. Soil should be dug away at the point of entrance and the pipe should be scraped and hammered if necessary.

### 13.4.3.3 Tank Roofs

All roofs should be checked for thickness, regardless of the external appearance. The inside surface of the roof plate is very susceptible to rapid corrosion because of the presence of corrosive vapors, water vapor, and oxygen. Ultrasonic instruments should be used to check roof thicknesses. Hammer testing can be used when ultrasonic instruments are not available or for further checking of very thin areas found during ultrasonic testing.

The hammer testing should be done with full blows of the hammer. A definite pattern of work should be followed to ensure complete coverage of all plates. After hammer testing, any damage to the paint should be repaired. Rust spots, depressions, bulges, holes, and other areas of obvious deterioration should receive special attention. The sound, feel, and imprint of the hammer blow are measures of the thickness of the plate struck. For badly corroded plate, the sound will be dull, the feel will be "soft", and the imprint may be a dent or even a hole. Figures 40 and

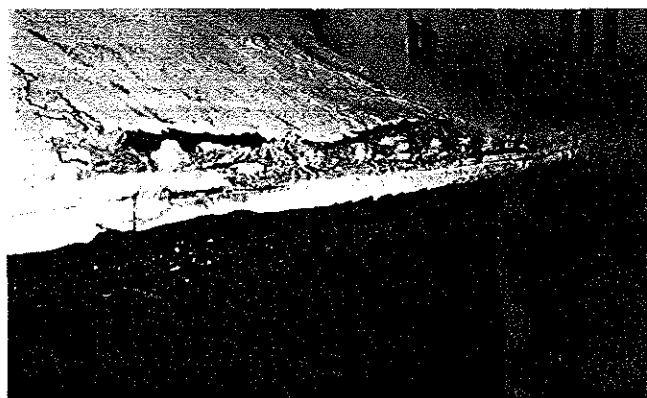


Figure 40—Example of Severe Corrosion of Lead-Lined Tank Roof

41 show examples of roof corrosion that progressed completely through the metal.

On cone-type, umbrella-type, and similar fixed-roof tanks; on pan-type floating roofs; and on the lower deck of pontoon-type floating roofs, the thickness testing preferably should be done before the bottom of the tank has been cleaned because considerable dust and rust may be dislodged from the inside of the roof. Also, the lower deck of pontoon roofs should be inspected before checking the upper deck, or it should be cleaned thoroughly if it is to be inspected after checking the upper deck.

In addition to checking the roof thickness by hammer testing, more accurate measurements of thickness should be made wherever convenient and in all areas where corrosion seems severe. This can be done in several different ways. Ultrasonic instruments are especially convenient because many measurements can be taken and the methods are nondestructive. These instruments can be used while the tank is in service. Also, test holes can be drilled and a hook gage used to measure the thickness. If the metal is more than 1/8-inch thick, the hole should be tapped and plugged after the measurement is taken. For thickness less than 1/8-inch, a rivet, a bolt and washer, or an expansion plug can be used to plug the hole. This hole may then be used for future measurements. Caliper measurements can be taken at manholes and other openings. If little or no corrosion is found, such measurements may be sufficient.

The interiors of the pontoons or double decks on floating roofs should be inspected visually by entering. Metal thickness measurements should also be taken. Some floating roofs have sandboxes for stability which should be checked to ensure that they are watertight. If the sand becomes saturated with water, corrosion will occur and the roof will not function properly. A good, portable light will be needed while doing this work.

The condition of the roof purlins (rafters) in fixed-roof tanks can often be checked through roof openings.

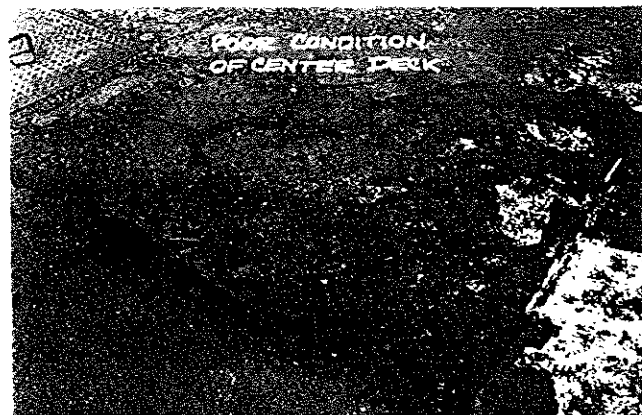


Figure 41—Center Pontoon of Floating Roof Corroded Through

Usually, these purlins can be measured with calipers. Unless severe corrosion of the purlins is evident, these measurements should suffice. Coupons approximately 12 inch by 12 inch in size can also be removed from the roof to check for underside corrosion and purlin condition.

While inspecting tank roofs for corrosion, a search for leaks should be made, although the best way to find leaks in the roof is with the low-pressure air test discussed later in this chapter. Leaks in pan-type roofs and in the center deck of pontoon-type roofs cause an economic loss because the leakage can drain away through the water drain. If the drain is blocked shut in any way in these types of roofs, leakage will eventually cause the roof to sink. If there is leakage into the pontoon of pontoon-type roofs or through the bottom deck of double-deck roofs, it can eventually cause the roof to sink. Leakage in the roof or in the pontoons can also cause the roof to become unbalanced and incur damage in subsequent binding during operation.

Before making a regular inspection of floating-roof seals, the drawings of the seals should be studied so that the operation is well understood. The points at which defects and troubles can occur will thus become more evident. In general, however, all seals should be inspected visually for corroded or broken parts and for rotted sealing materials. Any exposed mechanical parts, such as springs, hangers, counterbalances, pantagraphs, and shoes are susceptible to mechanical damage and wear and atmospheric or vaporspace corrosion. Figure 42 shows deterioration of a floating-roof seal.

Most floating-roof tanks are equipped with guides or stabilizers to prevent rotation. These guides are subject to corrosion, wear, and distortion and should be inspected visually. If the guides are distorted, this indicates that the roof has rotated excessively or has become jammed. The shell should then be inspected for buckles, as previously outlined in this chapter.

Roof drains on floating-roof tanks can be designed in many ways. They can be simple, open drain pipes or swing-joint and flexible-hose drains that keep the water from contaminating the products. Roof drains must function properly or certain types of floating roofs can sink or overturn. Figure 43 shows the severe damage that can result. This damage occurred while the roof was resting on the supports. The same type of failure can result from heavy snow or ice. This kind of damage can be prevented by keeping the roof floating. When the tank is out of service, the drain lines should be hammered thoroughly. Some drains are built in such a way that calipering is possible for measuring wall thickness. Otherwise, ultrasonic instruments can be used to measure the wall thickness. Any movable joints in the drain lines should be checked visually for wear and tightness. The drain lines, including the joints, can also be conveniently tested for tightness by

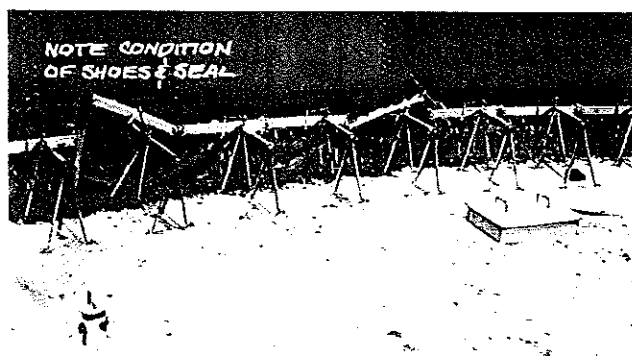


Figure 42—Deterioration of Floating Roof Seal

pressure testing with water. If it has been found by some that a two-stage test procedure is desirable. The first stage is a test at about 30 pounds per square inch gage pressure for approximately ½ hour to make any leaks in the pipe, hose, or rigid joints evident. The pressure is then dropped to approximately 5 pounds per square inch gage for another ½ hour to test the tightness of the swing joints. The latter appear to be self-sealing at the higher pressure but will leak at the lower pressure if defective. The drain lines can also be checked for blockage at the completion of the pressure test by merely opening the drain valve and observing whether the test water flows out freely.

Inspections of internal floating roofs may be difficult to accomplish if they are not of rugged construction. Planking may be required to walk on such roofs even if they are not corroded. A gas test should be made before personnel without respiratory equipment enter the tank. If there are no roof drains, adequate inspections should be made to ensure that stock does not leak onto the roof.

In addition to the pertinent inspections performed on floating roofs and cone roofs, the seals around columns and the ladder of internal floating roofs must be checked for leakage and workability. The ladder and columns should be checked for plumbness. The legs and leg sleeves should be checked for soundness and straightness.

#### 13.4.3.4 Valves

All valves on the tank should be inspected when the tank is out of service. The first outside valve on all connections should be examined visually to ensure that the seating surfaces are in good condition and that the body and bonnet are not seriously corroded. Where deterioration is indicated, thickness measurements should be taken. Water drawoff valves should be inspected to determine the type and condition. Possible damage by freezing should be considered.

Bonnet and flange bolts should be examined to see that they have not corroded and that they are tight.

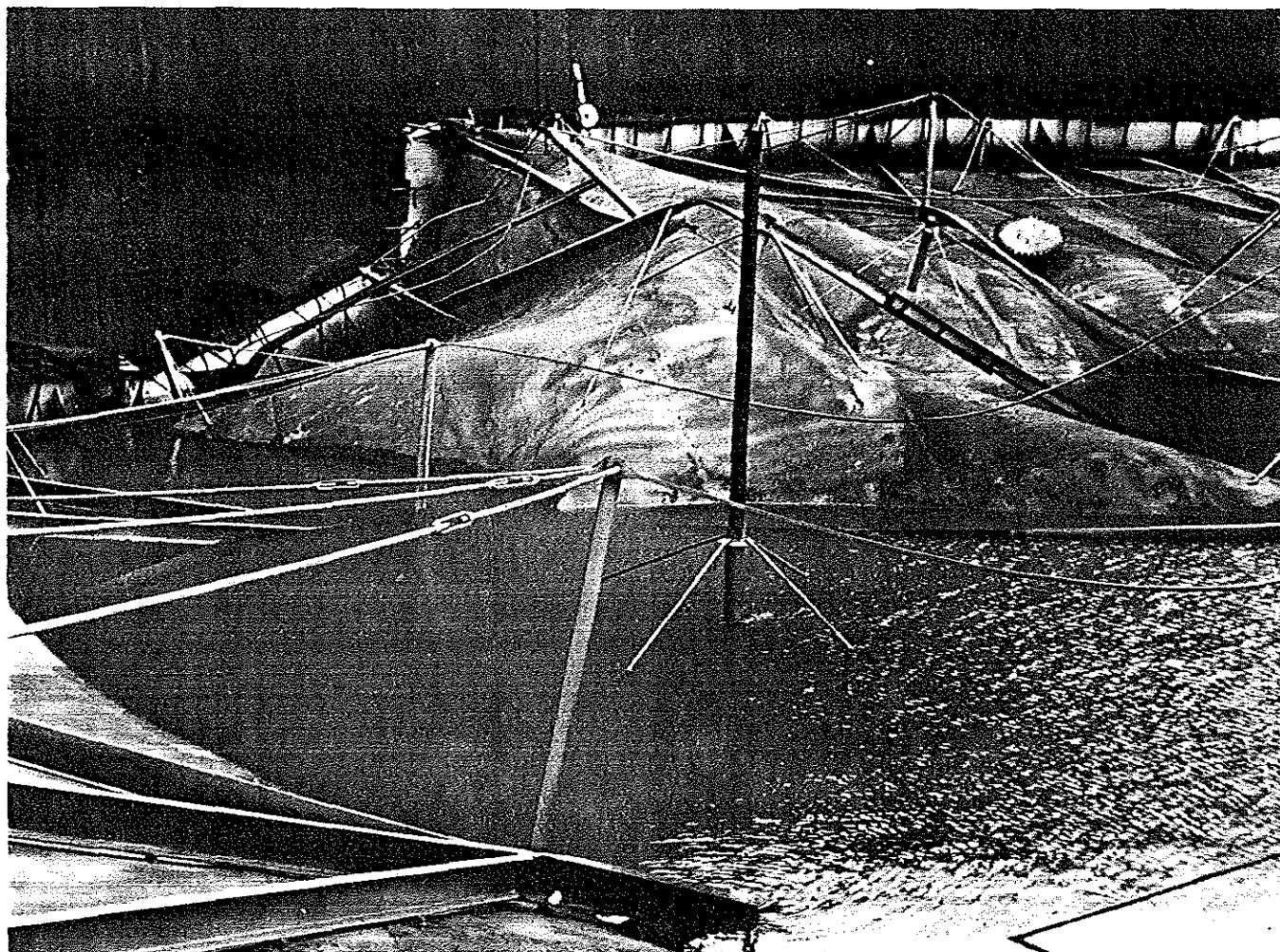


Figure 43—Collapse of Pan-Type Roof from Excessive Weight of Water While the Roof was Resting on Its Supports

#### 13.4.3.5 Auxiliary Equipment

Pressure vacuum vents and breather valves should be inspected to see that they are not plugged; that the seats are tight; and that all moving parts are free, not unduly worn, and not corroded. Thickness measurements should be taken where deterioration is indicated. The inspection of these valves is discussed in greater detail in Chapter XVI.

Liquid-level gaging equipment should be given a careful visual inspection. For float-type gages, the float should be examined for corrosion or cracks and to ensure that it does not contain liquid. Cables and chains should be inspected for corrosion and wear. Sheaves should be inspected to see that they turn freely and are properly lubricated. Guides should be examined to ensure that they are free and not plugged and any wooden parts should be checked for rot. Remote-reading indicators can be used instead of the simple gage board or directly coupled mechanical indicators.

The float, cables, pulleys, and other parts of this equipment are essentially the same as those for the simple type, except that the cable is connected to a transmitter that converts the mechanical movement into an electric current which is wired to a remote indicator. The transmitter and indicating equipment is similar to other instrument equipment that is discussed in detail in Chapter XV, "Instruments and Control Equipment." The manufacturer's instructions will be even more valuable with regard to methods of inspection.

If a pressure gage is used on a tank, it should be checked to see that the pipe connection to the gage is not plugged, that the gage is operative, and that its reading is accurate. For ordinary uses, the gage can be checked for reasonable accuracy by connecting it to a suitable source of pressure along with a gage known to be accurate. For test purposes, a deadweight tester or a calibrated test gage should be used.

### 13.4.4 INTERNAL INSPECTION

All internal inspection requires that the tank be out of service. To minimize out-of-service time, the inspection should be planned carefully. As previously stated, all necessary equipment such as tools, lights, ladders, and scaffolding should be assembled at the site in advance, and arrangements should be made to have all necessary mechanical help available. The necessity of adequate lighting for internal inspections cannot be overemphasized. The value of taking photographs for the inspection records should be considered.

#### 13.4.4.1 Precautions

The tank must be emptied of liquid, freed of gases, and washed or cleaned out as discussed previously in this chapter and in Chapter V. Microballons are sometimes used in cone-roof storage tanks. These are tiny, hollow plastic balls, approximately 0.0034 inch in diameter. A layer of these ballons floats on the surface of the stored liquid and acts as a vapor seal. The balloons must be removed from the tank if the tank is to be completely inspected.

#### 13.4.4.2 Preliminary Visual Inspection

A preliminary, general visual inspection is the first step in internal inspection. For safety reasons, the roof or top head and any internal supports should be inspected first. The shell and then the bottom should follow in that order for the preliminary visual inspection. If possible, the general pattern of any corrosion that is readily evident should be established in regard to the area in which it is located and the type (pitted or uniform). Ordinarily, the vapor space, the liquid-level line, and the bottom are the most likely areas in which corrosion will be found. Floating-roof tanks should be examined for loose or broken seal hangers which can cause abrasive wear.

#### 13.4.4.3 Types and Location of Corrosion

Internal corrosion of storage tanks depends on the contents of the tank and on the material of which the tank is made or lined. The most severe corrosive conditions exist in steel tanks storing corrosive chemicals or products. Corrosion may be rather uniform throughout the interior of such tanks. In ordinary refinery product service, the vapor space above the stored liquid is usually an area of heavy attack. This is caused by the presence of corrosive vapors, such as hydrogen sulfide mixed with air. The vapor-liquid line is another region that may be subject to rapid attack, especially when materials heavier than water are stored. Although such materials are not common in refinery storage, any water in such tanks will float on the material and accelerate corrosion. Figure 44 shows a clear-cut example

of vapor-liquid line corrosion. In this case, the stored material was 98 percent sulfuric acid (not corrosive to carbon steel at this high concentration). Moisture collecting in the tank produced a weak (corrosive) acid in the upper layer of liquid, resulting in the deep groove shown. When the stored material contains acid salts or compounds, they may settle to the bottom of the tank; and if water is present, a weak acid will form and cause corrosion. This will usually be a pitting type of attack. It often occurs in the top of tanks directly under holes or openings where water can enter, at breaks in mill scale, and adjacent to particles of scale that have fallen on the bottom.

Among the types of deterioration that occur on the shells of storage tanks are hydrogen blistering, caustic embrittlement, and cracking. They occur on the roofs and bottoms of tanks also, but less frequently at these points. Tank steel containing slag inclusions and laminations is most susceptible to hydrogen blistering. Caustic embrittlement may occur in tanks in which caustic is stored. Stressed areas are most susceptible to caustic attack. This type of attack is more prevalent when the temperature rises above 150 F. It is therefore most likely to occur around heating-coil connections.

Following the preliminary, general visual inspection, it may be necessary to do further preliminary work before a detailed inspection can proceed. Any parts or any material hanging overhead that could fall, including large areas of corrosion products on the underside of the roof, should be removed or otherwise made safe. In cases of severe corrosion of roof supports, it may be necessary to repair or replace the supports. Additional cleaning may be indicated: if large areas are severely corroded, it may be best to have them sandblasted clean. Normally, it will not be necessary to remove light coatings of oil or thin rust. After these operations are completed, the more detailed inspection can proceed.

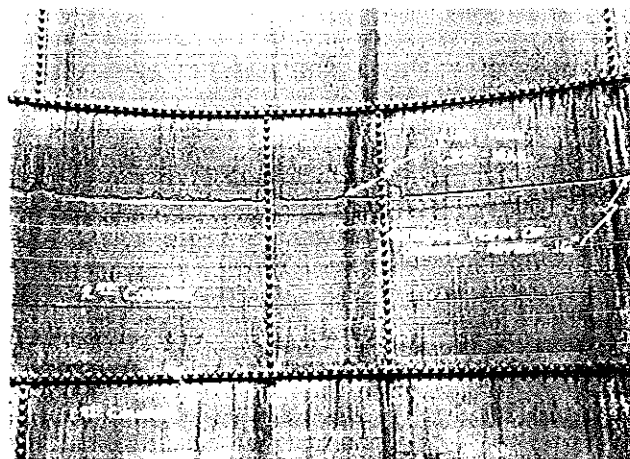


Figure 44—Example of Vapor-Liquid Line Corrosion

#### 13.4.4.4 Tank Bottoms

The tank bottom should be checked thoroughly for thickness over its entire area. Ultrasonic instruments are usually the first choice for obtaining the thickness measurements. If an ultrasonic instrument is not available, hammer testing can be used as an alternate method of checking the condition of the bottom.

Hammering can also be used to find and determine the extent of pits which are often hard to locate because deposits are packed into them. Hammering tends to pop this deposit out, making the pits easier to see. The bottom should be hammered thoroughly. This hammering should follow the same pattern as that previously described for the upper side of the roof. Corrosion pits and sprung seams should be looked for while hammering. Pits can sometimes be found by scratching suspected areas with a pointed scraper. When extensive and deep pitting is found and measurements in the pits are wanted, the areas may be sand-blasted. The depth of pitting can be measured with a pit gage or with a straightedge and steel rule (in large pits). An estimated depth can be found by extending the lead of a mechanical pencil as a simulated depth gage. Seams of welded tanks can be checked visually for leaks. Seams of riveted tanks can be checked by running a thin-bladed scraper or knife along the riveted seam. If the seam is open, the scraper will pass into the opening and disclose the fault. Rivets should be checked at random for tightness. Rivet heads should be checked visually for corrosion. This checking may involve considerable scraping and picking to clean the corrosion products from the head. Consideration should be given to determining whether enough of the rivet head remains to last until the next inspection. Figure 45 shows a special case of severe corrosion in the vicinity of a tank-bottom seam. The tank contents were acidic and were kept in motion with an agitator. The deterioration was probably a combination of corrosion

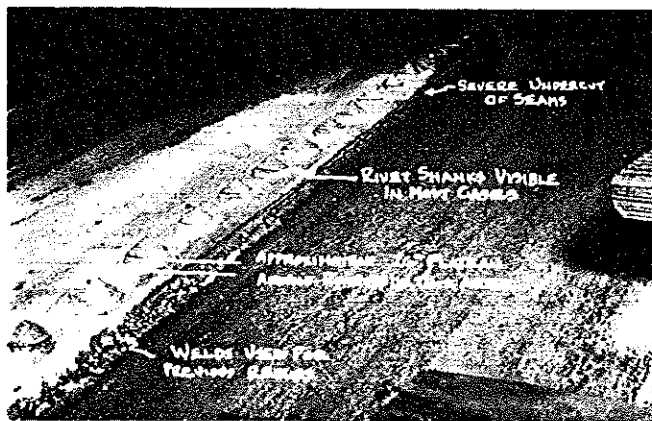


Figure 45—Localized Corrosion-Erosion at Riveted Seam in a Tank Bottom

and mild erosion, further accelerated by the high stresses in the area of the riveted seam.

Depressions in the bottom and in the areas around or under roof supports and pipe-coil supports should be checked closely. Any water that gets into the tank may collect and remain at these points, thereby causing accelerated corrosion.

Bottom thickness measurements should be obtained and recorded. The number of measurements taken will depend on the size of the tank and the degree of corrosion found. When little corrosion is observed, one to four readings per plate (depending on the tank size) should suffice. When severe corrosion exists, many readings may be taken in the attacked areas to determine the minimum remaining metal.

All corrosion products should be cleaned from the area. Test holes may be drilled and tapped; after the plate thickness is obtained by means of a hook gage, the holes may be plugged with bar-type, solid tapered threaded plugs. Being threaded and having a taper, these plugs can be removed for measuring purposes at subsequent inspections and can be easily tightened. The use of thread compound will ensure easy removal of plugs at a future inspection. The area adjacent to the plug should be inspected for corrosion during future internal inspections. This type of hole can also be drilled in the bottom of tanks resting on pads so that the space under the tank bottom can be freed of gas. When holes are drilled for that purpose, they can also be used for thickness measurements. The ultrasonic instrument can also be used to measure the bottom thickness with good accuracy, except in severely pitted areas. This instrument is very useful when many measurements are desired, such as in extensively corroded areas. An example of extensive bottom corrosion is such shown in Figure 46.

Corrosion on the underside of flat-bottom tanks resting on the soil or on pads cannot be checked easily from the outside. From the inside the corrosion may be detectable by hammering. Erratic readings with the ultrasonic instrument are also an indication of underside corrosion. When a positive inspection and accurate checks are desirable, it is best to cut out representative sections or coupons (at least 12 inches in least dimension) of the bottom plate. One method is to cut the first coupon 12 inches by 12 inches, the second 14 inches by 14 inches and to increase the size of each additional coupon. This permits all but the smallest coupon to be used as a patch for the next smaller size cut-out. The only new material to be cut will be for covering the largest cutout. The underside of the removed coupon can be inspected easily. If very severe corrosion is found, the removal of additional coupons in other areas may be indicated.

Water drawoff elbows are, of course, subject to internal and external corrosion as well as cracking. They are especially subject to cracking if they are cast iron. They should

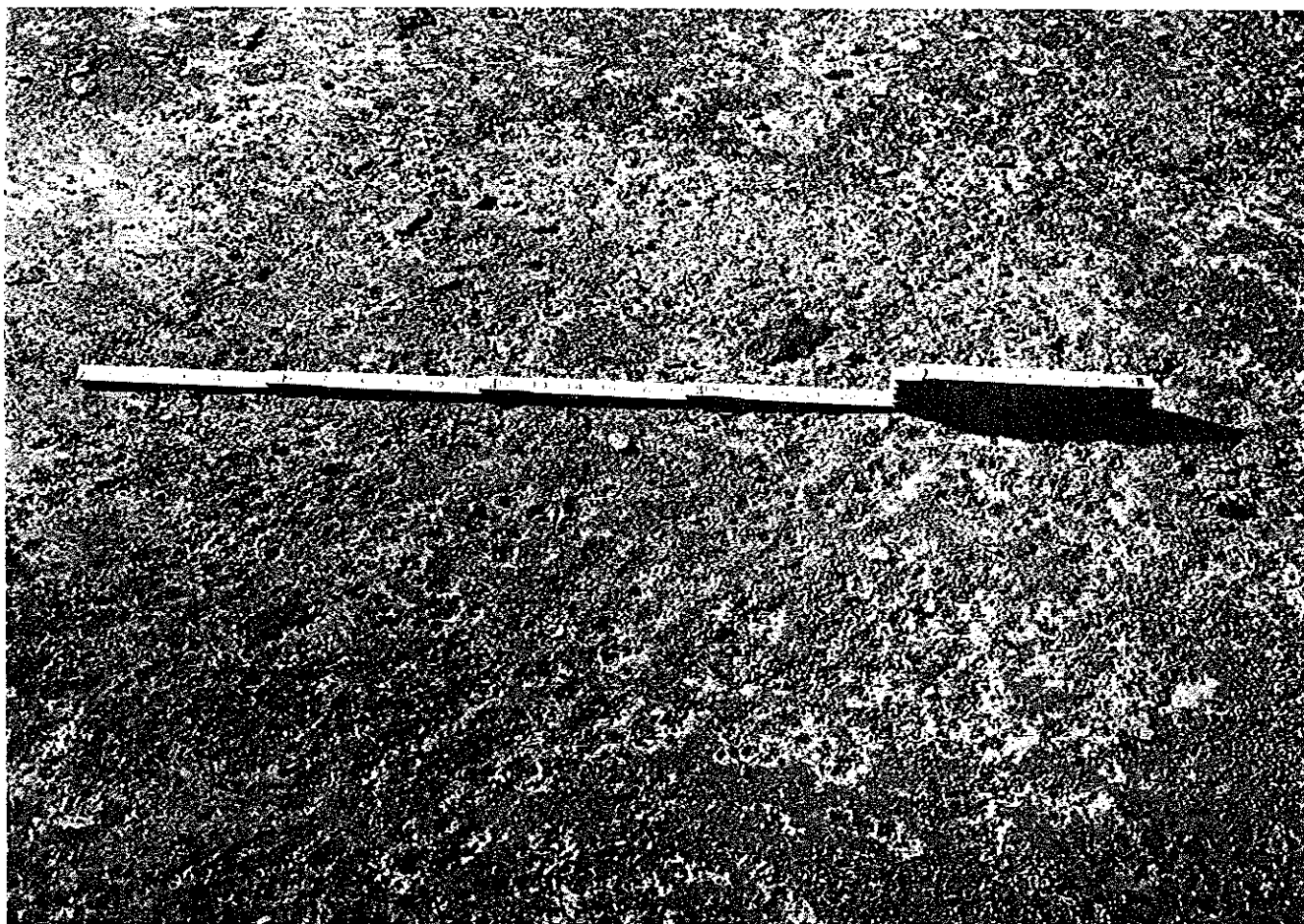


Figure 46—Example of Extensive Corrosion of a Tank Bottom

be visually inspected to the extent possible. Conversion to a water drawoff sump of the type illustrated in API Standard 650 may be desirable under certain conditions.

The bottom should be checked visually for damage caused by settling. Excessive unevenness of the bottom indicates that this type of damage has occurred. Well-suction pots should be examined for both internal and external corrosion.

#### 13.4.4.5 Tank Shell

Some tanks may have a bottom angle between the shell and the bottom, as shown in Figure 47. The shell adjacent to any welded butt joints in this angle should be checked for cracks. The areas should be sandblasted, and the dye penetrant or magnetic-particle method should be used.

Interior sources of leakage noted during external inspection should be investigated where feasible and necessary.

The shell should be inspected visually for signs of corrosion. The service and contents will determine the areas of corrosion. The vapor space and liquid-level line are likely

areas of corrosion. However, if the walls are alternately wet and dry, or the contents are corrosive chemicals, the entire shell can be attacked. Figure 48 shows an example of vapor-space corrosion. Figure 49 shows an example of a tank shell corroded completely through as a result of corrosion, with a mild erosion produced by the action of an agitator in the tank. When severe corrosion is found, measurements should be taken to supplement those measurements obtained from the outside. As this work is usually done from a ladder, the ultrasonic instrument is the most convenient method to use. For large, tall tanks, a "tank buggy"—a scaffold mounted on wheels—can be used, as shown in Figure 50.

While inspecting the bottom, the roof, and particularly the shell of the tank for corrosion, the plate joints and nozzle connection joints, especially on welded tanks, should be inspected carefully for any evidence of cracking. A strong light and a magnifying glass will be very helpful in doing this work visually. A combination flashlight and magnifying glass, described in Chapter IV, is a convenient tool for the purpose. If any evidence of cracking is found,

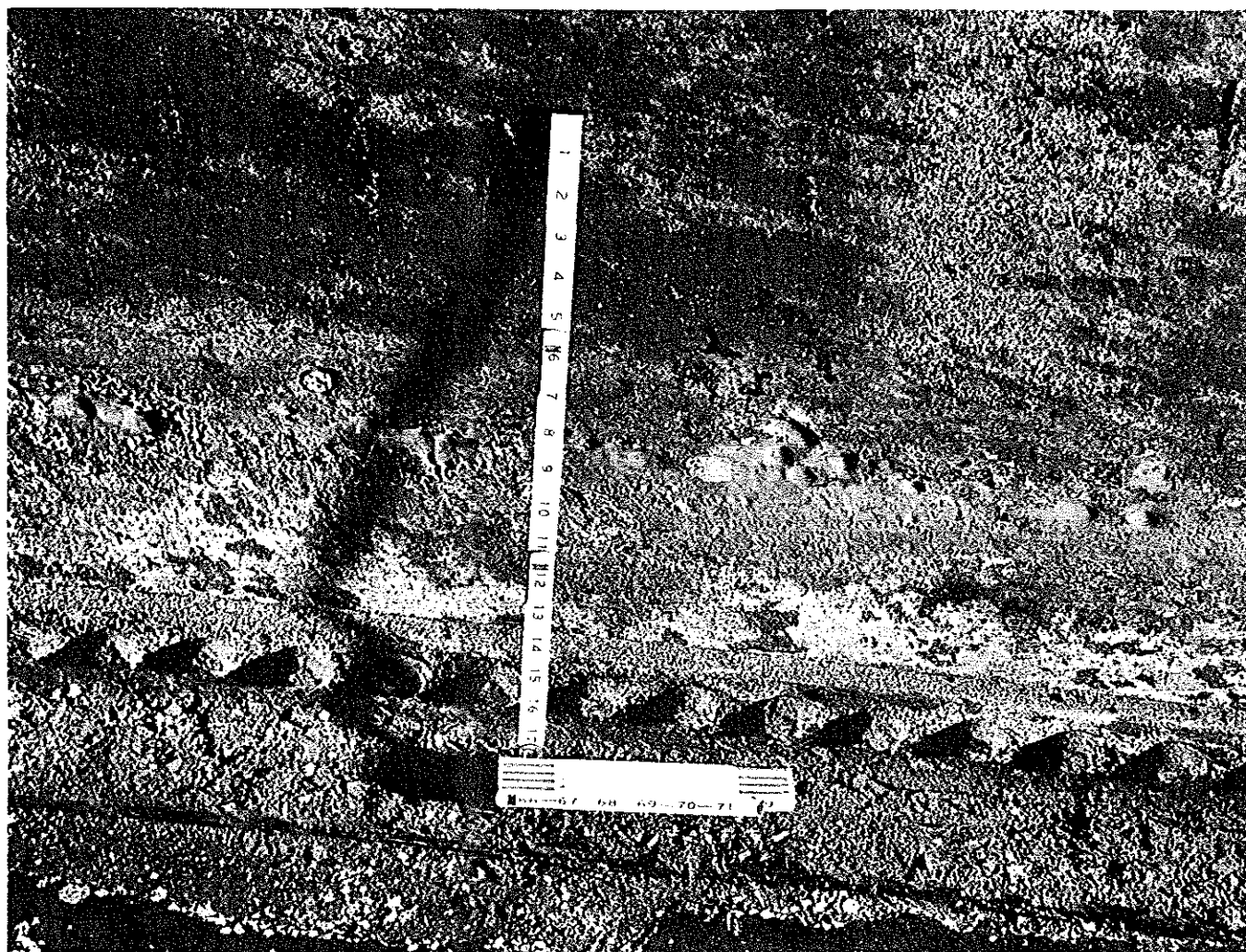


Figure 47—Bottom Angle Between Bottom and Shell (Also Shows Deep Pit Corrosion in Shell)

a more thorough investigation using the magnetic-particle, dye penetrant, or radiographic method may be necessary. These methods of inspection have been described in detail in Chapter IV.

#### 13.4.4.6 Testing for Leaks

A search for leaks through the bottom or through the shell should also be done. If the tank is to be tested during the course of the inspection, the test itself will be the best method for detecting leaks. If a test is not to be made, a penetrating oil (such as automobile-spring oil) can be sprayed or brushed on one side of the plate in suspected areas, while the other side is then observed for leakage. The dye penetrant method used for finding cracks can also be used in much the same manner, with the dye applied to one side of the plate and the developer applied to the other side.

Another method for finding leaks—which is particularly useful on the flat bottom of a tank, but can also be adapted to the shell—is the use of the vacuum box shown in Figure 51 and 52. In this method the suspected area is first coated with a rich soap solution or other suitable leak-testing liquid; in cold weather it is important that the leak-testing liquid has been formulated for use at the temperature involved. The open side of the vacuum box is then pressed tightly over the area, with soft gaskets placed between the tank plate and the box edges. A vacuum is developed inside the box by means of a vacuum pump or air ejector connected to the box through a hose. Leakes will appear as soap bubbles when looking through the glass top of the vacuum box.

The bottoms of tanks resting on pads or on the soil can be inspected for leaks in several other ways. In each of the methods a temporary clay dam or seal is placed around the outside of the tank at the bottom. In one method the inside



Figure 48—Example of Vapor Space Corrosion

surface of the bottom is coated with soap solution; air which can not exceed 3 inch of water pressure is injected by hose under the bottom of the tank through the clay seal or through a drilled and tapped hole (or holes) in the bottom. The bottom is then inspected for soap bubbles which will indicate any leaks. A second method consists of pumping water under the tank (holding it with the clay dam) to a depth of approximately 6 inches above the level of the highest point of the tank bottom. Vents are required to allow trapped air to escape. Leaks will then be evident as the water seeps through to the inside of the tank. A third method consists of pumping approximately 6 inches of water into the tank and then placing not more than 9 inches of water pressure of air under the tank. Leaks will be evident as air bubbles through the water in the tank. The effectiveness of these methods can be improved by covering the entire bottom with an air-operated hammer. The sharp jarring

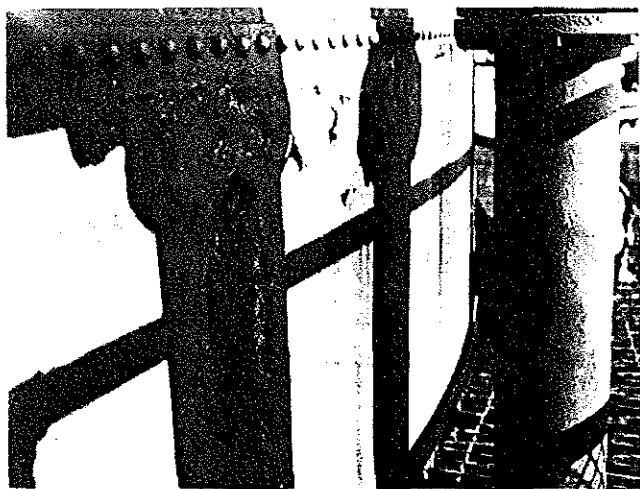


Figure 49—External View of Corrosion-Erosion Completely Through a Tank Shell

of the bottom plates will frequently cause enough scale to pop out of pits to allow them to leak.

The second method described in the preceding paragraph—pumping water under the bottom—can cause the tank pad to wash out or shift, depending upon its construction. When using air under the tank, a considerable amount of plastering of the clay seal may be needed in order to build up the air pressure to the desired value. When the third method is used, the water must be pumped into the tank before air pressure is applied under the tank.

Steam is used as a test medium for tanks that have stored wax, asphalt, and similar materials.

#### 13.4.4.7 Linings

When the inside surfaces of a tank are lined with a corrosion-resistant material, such as sheet lead, alloy steel, rubber, organic and inorganic coatings, glass, or concrete, the inspection methods are somewhat different. Figures 53, 54, and 55 show the severe deterioration that can take place when leakage occurs. The most important consideration is ensuring that the lining is in good condition, that it is in proper position, and that it does not have holes or cracks. Usually, lead linings are used only in tanks containing extremely corrosive materials, such as dilute acids;

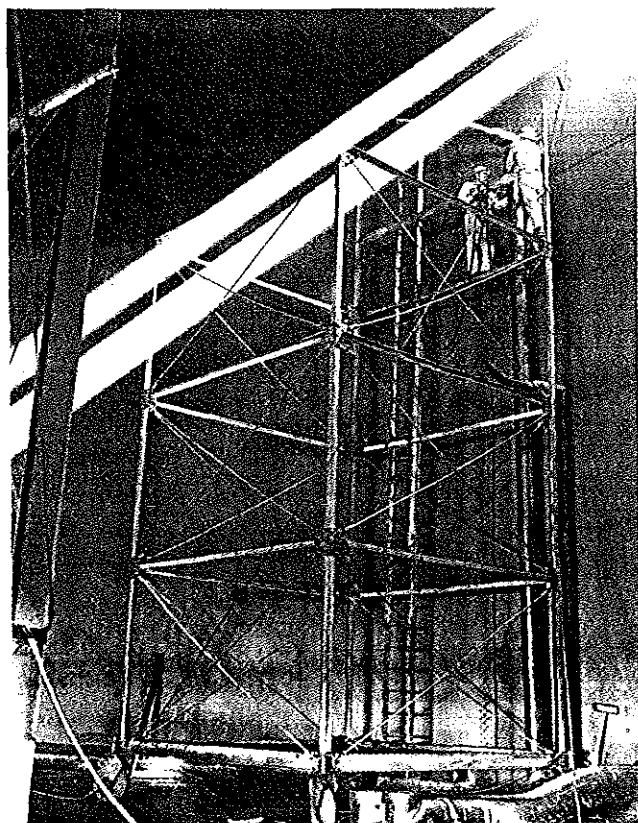


Figure 50—Tank Buggy Used for Inspection and Repairs Inside Tank

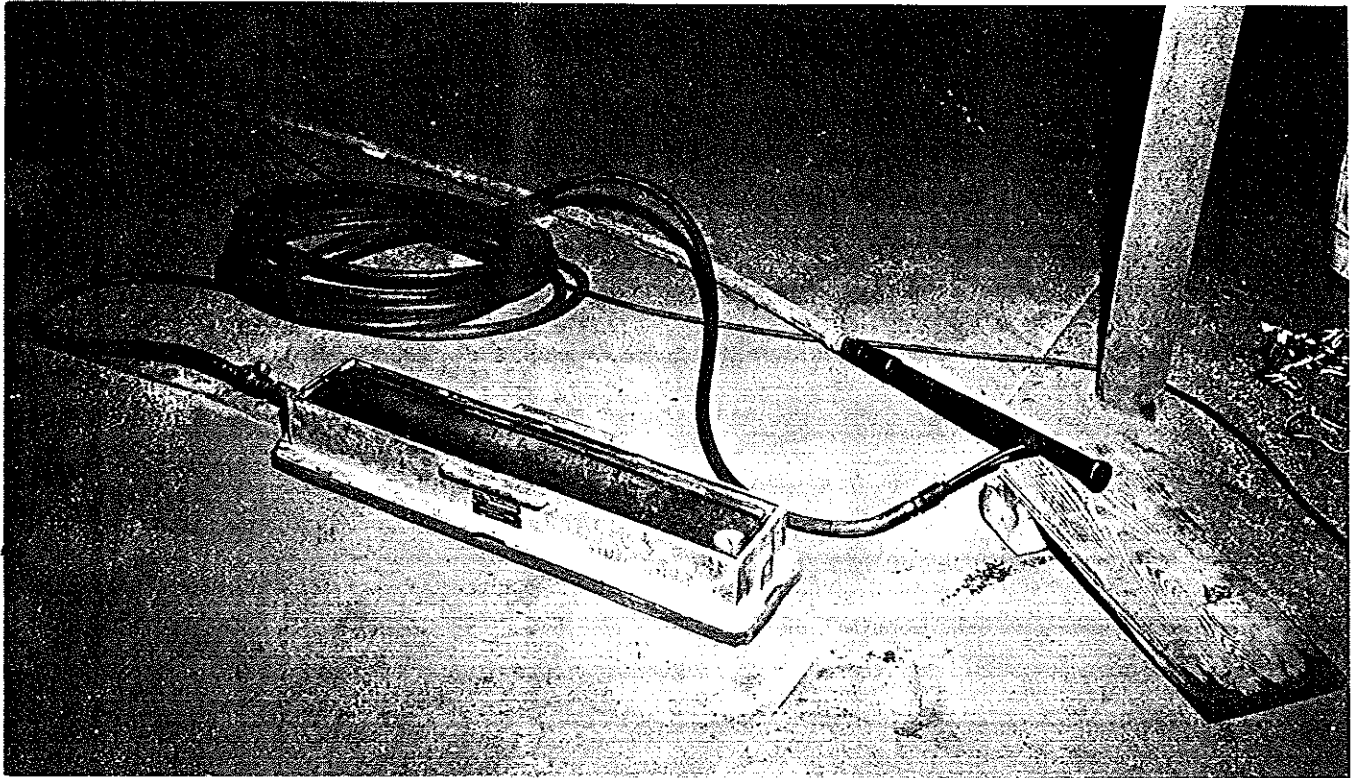


Figure 51—Vacuum Box Used for Testing Leaks

hence it is very important that there be no openings in the lining through which the corrosive liquid can reach the steel of the tank. The best way to inspect lead linings is by lightly scraping any suspected areas with a knife or other

scraper. The scraping will remove the thin, dark lead oxide, expose the bright lead underneath, and, by contrast, show any defects. Dye penetrant is very effective in locating pinholes and tight cracks in lead linings. Joints in the sheet-lead lining are particularly susceptible to opening. Bulges in the lining are an almost positive indication of leakage behind the lining and, at best, indicate a deterioration of the mechanical condition of the lining.

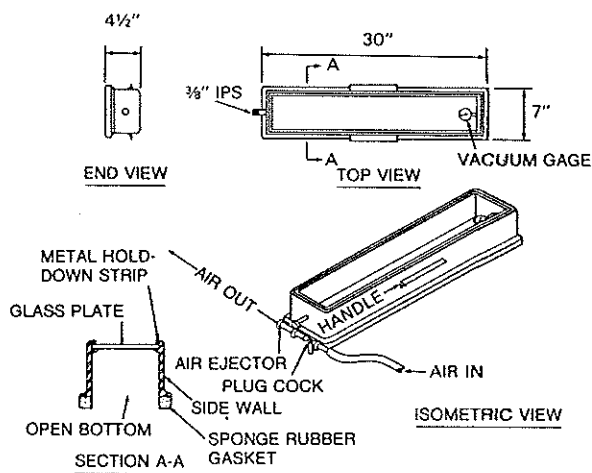


Figure 52—Vacuum Test Box for Detection of Leaks in Vacuum Seals



Figure 53—Deterioration of Lead Lining on Roof of Tank Caused by Leaks in Lining

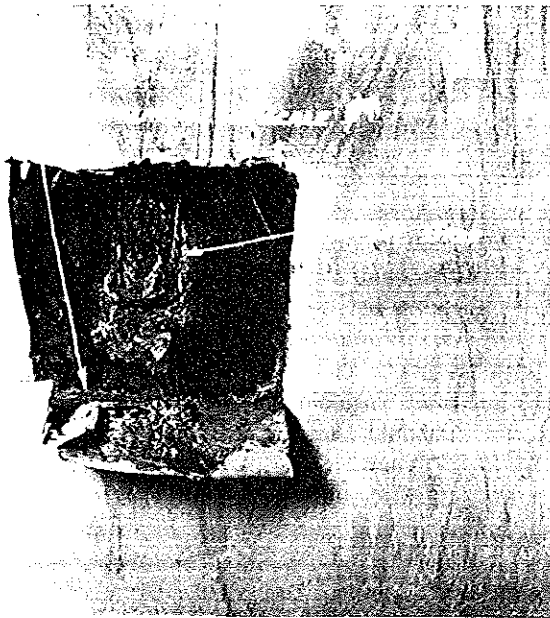


Figure 54—Condition of Steel Behind Lead Lining Shown in Figure 53

With alloy steel or more rigid metal linings such as nickel and monel, inspections should be made for leaks or cracks in the lining joints. A careful visual examination is usually all that is required. If there is evidence of cracking the dye penetrant method can be used with such materials. The magnetic-particle method cannot be used on nonmagnetic lining material.

With rubber, glass, and organic and inorganic linings, the general condition of the lining surface should be inspected for mechanical damage. Holes in the lining can be evidenced by bulging, blistering, or spalling. A thorough method of inspecting for leaks in such linings is the use of a high-voltage, low-current electrode that is passed over

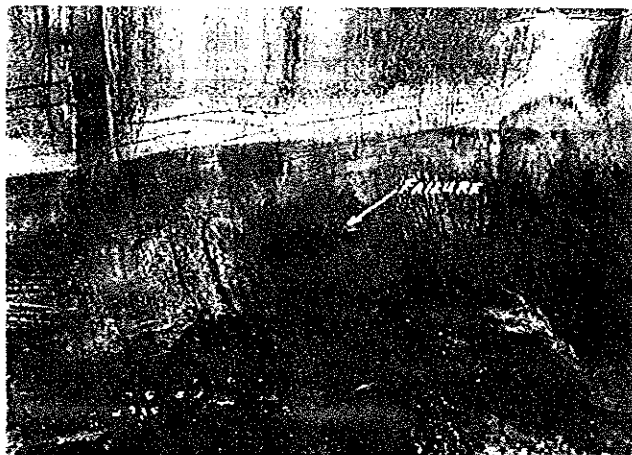


Figure 55—Failure in Lead Lining at Bottom Knuckle of Tank

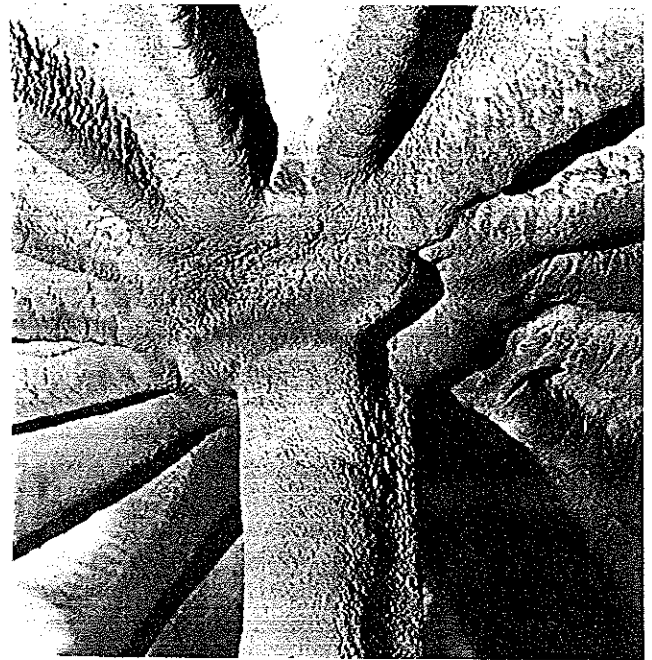


Figure 56—View of Pneumatically Applied Concrete Lining on Rafters, Center Column, and Roof of Tank

the nonconductive lining while the other end of the circuit is attached to the steel of the tank. This is commonly called a "holiday" detector. An electric arc will form between the brush electrode and the steel tank through any holes in the lining. Caution must be used so that the test voltage does not approach a value that might puncture the lining. The method is described in more detail in Chapter IV.

In order to avoid mechanical damage to the linings, considerable care should be taken when working inside tanks lined with lead, rubber, glass, or organic or inorganic coatings. Glass-lined tanks are especially susceptible to severe damage that cannot be easily repaired. Glass-lined vessels should never be hammered or subjected to any impact on the inside or the outside because the lining can crack. It is advisable to paint them a distinctive color as a warning against striking them. It is important to keep spillage off the outside of glass-lined tanks. Corrosion from spillage can result in hydrogen penetration and cause spalling of glass liners.

Concrete linings, which are rather commonly used and which are usually applied pneumatically, are rather difficult to inspect thoroughly. A view of a concrete lining is shown in Figure 56. Mechanical damage, breakage, spalling, major cracking, bulging and complete falling-away of the lining are readily seen. Minor cracks and areas of porosity are more difficult to find. In some instances they may be seen as rust spots on the surface of the concrete which are caused by steel corrosion products leaking

through the lining. In almost all cases of corrosion occurring behind the lining, the concrete will lose its bond with the steel and will be evident by light hammer tapping.

If doubt exists as to the condition of metal or concrete linings or the steel behind the lining, a section of the lining can be cut out for more detailed inspection. If corrosion is found, more sections can be checked.

#### 13.4.4.8 Roof and Structural Members

Ordinarily, a visual inspection of the roof interior and supports is sufficient. When corrosion or distortion is evident, scaffolding should be erected so that measurements can be taken.

When local corrosion has been found on the inside of the shell, any roof-support columns should be checked closely at the same level. Transfer calipers and steel rules may be used in measuring structural members. Measurements should be checked against the original thickness or the thickness of uncorroded sections. If corrosion or distortion of the members is evident, structural welds and bolting should be examined to determine the extent of damage. Light hammer taps can be used to test the tightness of bolts and thickness of structural members. Figure 57 shows the results of failure of wooden roof supports.

The underside of floating roofs and of internal floating roofs should be inspected for corrosion and deterioration

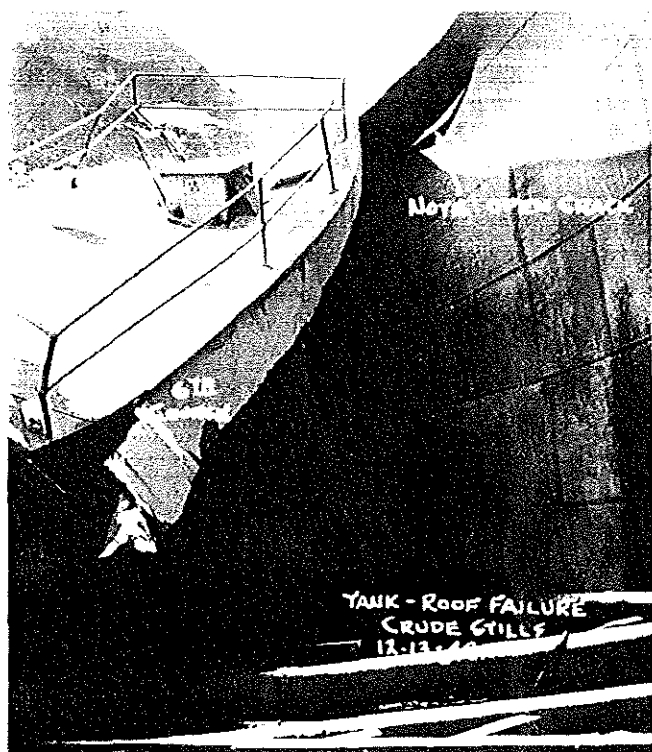


Figure 57—Result of Failure of Wooden Roof Supports

not seen during the topside inspection that is described in 13.4.3.3. Vital parts of some roof seals can only be inspected from the under side.

#### 13.4.4.9 Internal Equipment

Any internal equipment such as pipe coils, coil supports, swing lines, nozzles, and mixing devices should be visually inspected. Coils and supports should be checked for corrosion, warpage, and cracking. Except for cast iron parts, the coils and supports should be hammer tested. If wooden coil supports are used, they should be checked with a scraper or knife for rot, and the bottom should be checked for corrosion under the wooden supports. Consideration should be given to replacing the wooden supports with steel supports. Coils should be tested hydrostatically for leaks. If cracks are suspected in the nozzles or nozzle welds, they should be checked by the magnetic-particle or dye penetrant method. Figure 58 shows a typical installation of heating units in a tank, and Figure 59 shows an example of heating-coil corrosion.

The swing lines on floating-roof tanks may be equipped with pontoons, rollers, and tracks. The pontoons should be hammered and checked for leaks. The thickness of the pontoon wall can be measured with ultrasonic instruments. The tracks and wheels should be inspected visually for corrosion, wear, and distortion. The roof in the area of these tracks should be checked for bulging, which can occur if the swing-line pontoons create an extensive upward thrust.

If the connecting pipelines carry corrosive products or if there is any other reason to expect high internal metal loss, the thickness of the tank nozzles and pipe walls should be measured with ultrasonic instruments. Visual examination of the lines can be made by opening the line at the flange connection closest to the tank. Caliper measurements of the pipe can be made if a joint is opened. This will require emptying the line and blanking it at some point beyond the

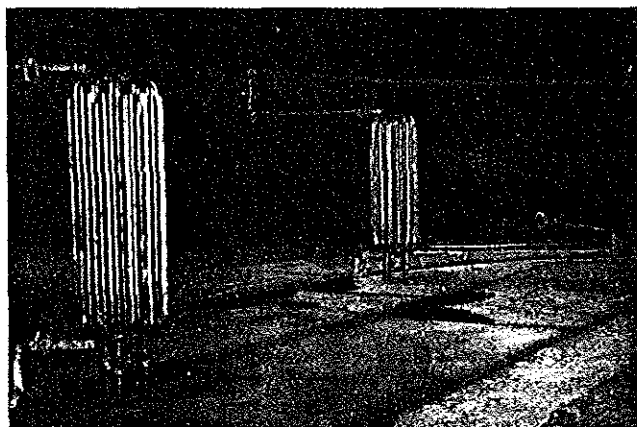


Figure 58—Fin-Tube Type of Heaters Commonly Used in Storage Tanks

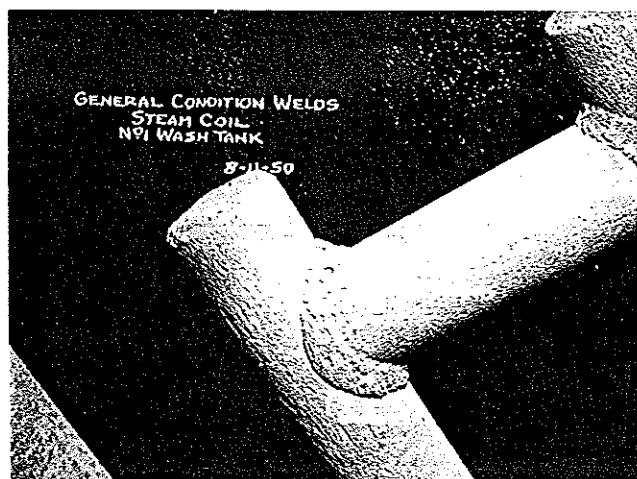


Figure 59—Example of Corrosion of Steam Heating Coil

opened joint. Gasket surfaces of opened flanges should be checked for corrosion, and the flange faces should be checked for distortion by using a flange square. Nozzle thickness can be calculated by measuring the inside and outside diameters. This method avoids breaking the joints. As corrosion may be greater on one side of the nozzle, a visual check for eccentricity of the nozzle interior should accompany these measurements and calculations.

### 13.4.5 TESTING OF TANKS

When storage tanks are built, they are tested in accordance with the standard to which they were constructed. The same methods later can be used to inspect for leaks and to check repair work. When major repairs or rebuilding have been done, such as the installation of a new tank bottom or replacement of large sections of shell plate, the need for a test should be considered. High quality materials, design details, fabrication procedures, or nondestructive examination may be considered in lieu of testing. If the repairs have not made the tank as strong as a new tank, the water height for the test should be limited in accordance with the lower strength conditions.

The word *testing* as used in this section applies only to the process of filling the tank with a liquid or gaseous fluid, at the appropriate pressure, to test it for strength and leaks.

Atmospheric storage tanks, which are designed to withstand no more than 0.5 pounds per square feet gage pressure over the static pressure of the liquid contained in the tanks, are normally tested only by filling the tanks with water. The strength of the lower portions of a tank is thus tested at a pressure that depends on the depth of water above. All exposed portions of the tank can be checked for leaks; up to the water level even serious leaks in bottoms

resting on pads can be detected. For certain high-strength and alloy steels, consideration should be given to water ingredients and contaminants, such as chlorides, to avoid the possibility of stress corrosion cracking (see Chapter II, *"Conditions Causing Deterioration or Failures"*). Consideration should also be given to the notch toughness of the shell material at the air and water temperature existing at the time of the test. A discussion of notch toughness and brittle failures also can be found in Chapter II. If water is not available and if the roof of the tank is reasonably airtight or can be made so, a slight air pressure not exceeding 2 inches of water pressure may be applied to the inside of the tank. This type of test is of very little use as a strength test and is used only in inspection for leaks. Soap solution is applied to the outside surface of all suspected areas of the tank, especially on the seams, so that the air escaping through the leaks will produce soap bubbles, thus disclosing the leaks. Roof seams can be effectively vacuum-tested in the same manner.

Low-pressure storage tanks can be tested in the same manner as atmospheric storage tanks, but at slightly higher pressures, depending upon their design (see API Standard 620).

Pneumatic testing can be used when water or other suitable liquid is unavailable, when a tank is unstable when filled with liquid, or when a trace of water cannot be tolerated in the normally stored product. If a tank is seriously corroded, this method should be avoided; however, if it is necessary to use the method, the greatest caution should be exercised. Inspection for leaks can most easily be made by soaping the outside seams of the tank and looking for soap bubbles, as in atmospheric tanks.

### 13.4.6 DETERMINATION OF LIMITS

The inspection of storage tanks is much more valuable when the limits of corrosion and other forms of deterioration that can safely be tolerated are known for the tank being inspected. There are two aspects to consider when inspecting a tank: (1) the rate at which deterioration is proceeding, and (2) the safe limit of deterioration. For the most common form of deterioration, metal corrosion, the rate of metal loss in a tank in any given service can be obtained by plotting the metal thickness at two or more inspections against the inspection dates, as shown in Figure 60. An extension of the line drawn through the plotted points will indicate, with reasonable accuracy, the time at which the metal will reach the limit of deterioration. Most other forms of deterioration—such as mechanical damage from wind, cracking of the tank metal, and operating failure of accessories—do not take place at a steady rate; in fact, they are unpredictable. If the safe limit of deterioration is known, knowing how long the tank will take to

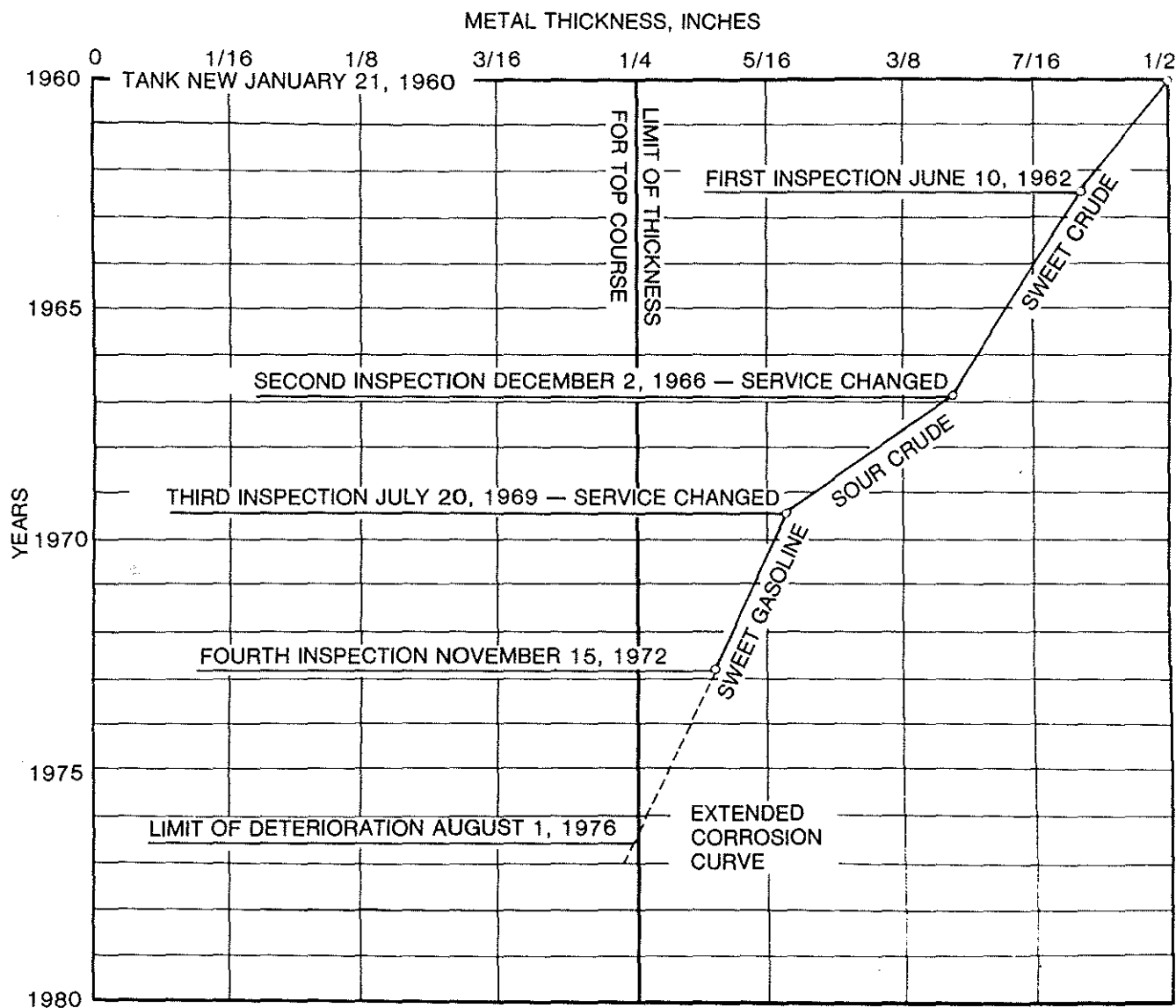


Figure 60—Hypothetical Corrosion Rate Curves for Top Course of Storage Tank

reach that limit is very important. If the limit appears to be in the near future, repairs or replacements may be necessary immediately. If that limit is farther in the future, it may be possible to postpone the repairs until the next scheduled inspection or to reschedule the next inspection period accordingly.

Obviously, when the safe limit has been reached, some action must be taken. Refinery operations demand a minimum out-of-service time for many storage tanks. Decisions as to serviceability or repairs of a tank must often be made during a single workday period or over a weekend. Thus, the minimum metal thickness should be known for each tank, or the methods of calculating the minimum thickness under any given set of conditions should be well

known. The limits of other forms of deterioration usually will have to be determined on the basis of good judgment and a knowledge of all the conditions involved.

Because of the large number of variables affecting the minimum thickness and the great variety of sizes, shapes, and methods of tank construction, it is not possible in this guide to present a set of precalculated minimum or "retiring" thicknesses. However, the preparation of such a set of tables is possible for all tanks in a given refinery, and it may be desirable to include this set among the tank records.

Methods for determining the "new" thickness of storage tanks are given in the standards or codes by which the tank was constructed. Most of these standards are listed in

13.1. In most cases, the new thickness includes some excess thickness over the absolute minimum required to withstand the internal pressure in the tank (produced by the weight of the stored fluid plus the vapor pressure, if any, on the liquid). This excess thickness may be the result of any one, or all, of the following factors:

1. Excess thickness deliberately added in the design as a corrosion allowance.
2. Excess thickness as a result of using a nominal thickness of plate, rather than the exact (smaller) value calculated.
3. Excess thickness as a result of deliberately setting minimum thicknesses of the plates for construction purposes.
4. Excess thickness as a result of arbitrary minimum thicknesses specified by the standards (for example bottoms and roofs of atmospheric tanks).
5. Excess thickness in the upper portions of shell courses.
6. Excess thickness available as a result of a change in tank service.

A corrosion allowance is sometimes added to atmospheric storage tanks. In large, low-pressure storage tanks the practice is more common.

The excess thickness described under the second factor will normally be rather small, but with low corrosion rates it can be important.

The plate thickness of a new large tank may be greater than required for the service so that the tank constructor may erect the tank more easily.

The bottoms of tanks resting on pads and the roofs of atmospheric storage tanks are subjected to practically no membrane stresses from pressure loads. Bottoms, away from the shell joint, need be only thick enough to be tight; the roof must also be thick enough to support its own weight plus design live loads between rafters. These parts are often made considerably thicker than necessary in service.

Because in all liquid storage tanks the pressure exerted on the sides of the tank by the weight of the liquid contained is greatest at the bottom and uniformly decreases up to the liquid level, at least a portion of all shell plates (the courses above the bottom course) is thicker than needed for the service. For flat bottom cylindrical tanks, the calculation of required thickness of the bottom course and the bottom part of the second course can be completed. See Appendix K of API Standard 650. If corrosion should occur in the bottom course or in the upper portions of an upper course, excess thickness may be available to allow the tank to remain in service longer than it normally might.

Storage tank wall thicknesses are normally designed to contain a specified fluid (usually water in the case of atmospheric storage) and with a specific vapor pressure added—0 to 0.5 pounds per square inch gage for atmo-

spheric storage tanks and from 0.5 to 15 pounds per square inch gage for low-pressure tanks. If the actual service conditions are different from those contemplated in the design, for example, either a lighter weight stored fluid or a lower vapor pressure, or both, the walls will have an excess thickness. Conversely, if the walls have corroded, it may be necessary to reduce the allowable filling height of the tank or the gravity of the material stored in the tank, in order to keep the tank in use; or, if the service conditions are less severe, the tank may be continued in the same service for a longer period.

In determining the limiting thickness for the plates of a tank, either for the purpose of precalculating a set of retiring thicknesses for each tank or as a matter of necessity at the time of inspection, the basic method given in the applicable standard should be used, and all the factors enumerated and discussed in the preceding paragraphs should then be considered and applied. The result will be a thickness that will be the minimum for the particular location for the given tank. When that thickness is reached, repairs or replacement will be required. In this connection it should be kept in mind that a pit or a very small area corroded to the retiring thickness does not weaken the plate appreciably from the standpoint of resisting pressure. The average thickness over a distance in a longitudinal direction equal to  $(Rt)^{1/2}$  (where  $R$  is the radius and  $t$  is the minimum allowable thickness, both in inches) is a good rule to follow in establishing a plate thickness for a corroded area. Repairs to such areas are required only to prevent leakage when corrosion progresses completely through the plate.

The roofs and bottoms of atmospheric storage tanks resting on soil or on pads have new thicknesses which, because they are not subjected to pressure differentials, are set rather arbitrarily by the tank standards. These plates can be allowed to corrode almost completely through, short of leakage.

For many parts of atmospheric storage tanks, neither the required thickness nor the methods for calculating the thickness are given in the tank standards. Such parts include pontoons, swing lines, water drawoff lines of floating roofs, nozzles, valves, and secondary structural members. Roof supports, wind girders, platforms, and stairways are covered by rules in API Standard 650.

For structural members and parts, such as roof supports and platforms the usual textbook methods for structural design can be used to calculate the allowable loads of members in the new condition.

For external pipe, nozzles, and valves, the methods given in American National Standards Institute<sup>1</sup> piping standards can be used.

<sup>1</sup> American National Standards Institute, Inc., 1430 Broadway, New York, N. Y. 10018.

A minimum thickness should be established for internal piping and nozzles that would set the retirement thickness for replacement prior to the occurrence of leaks.

Good judgment is of great importance in determining the limits of deterioration—whether it be corrosion or other forms—and experience is the best guide. The two most important factors to be considered in the decision to approve or condemn a tank or part of a tank are safe operation and loss of product. Because of the flammability of most materials stored in refinery tanks, the leakage of product can also produce an unsafe operation.

Some forms of tank deterioration are of such a nature that the decision to condemn for repairs or replacement can be almost automatic. Foremost among these is a significant amount of cracking in shell-plate seams. Because of the possibility of the cracks progressing rapidly, they should always be repaired before the tank is placed back in service. Serious mechanical damage, inoperable auxiliary equipment, damaged linings, and leaks are also conditions to be remedied before the tank is used again.

## 13.5 Methods of Repair

### 13.5.1 GENERAL

Since repair and maintenance are not a part of the inspection problem, no attempt has been made here to discuss such methods thoroughly. Repairs made to those parts of the tank which can be considered pressure parts and which properly require reinspection for safety reasons are discussed briefly. Some special methods of repair and acceptable temporary repairs are also included.

### 13.5.2 REPAIRS REQUIRING REINSPECTION

Before any repairs are made on tanks, the applicable codes, standards, rules of construction, and jurisdictional requirements should be well known so that the method of repair used will not violate the rules used in the original construction.

Many repairs on tanks will affect the strength or safety of the tank, and thus come under the applicable rules that require reinspection after the repair is completed. Generally, it is also good practice to make a quick visual check of all other repairs to see that they have been made properly. If all defects requiring repairs have been marked and recorded in a field notebook at the time of the original inspection, this recheck can be made easily.

Repairs made by welding on the bottom, shell, or roof of a tank should be inspected. The welding inspection methods should follow the procedures outlined in the appendix, "*Inspection of Welding*." Inspection should be made to see that the work is done completely and properly. Normally, a visual inspection will be sufficient. However,

magnetic-particle or dye penetrant methods can also be used; or, if it is convenient and believed necessary, radiographic methods may be used. Samples of the new weld metal can also be removed by means of a trepan saw or by the weld prober for a careful check of the weld quality. Sample removal requires repair of the hole that remains and therefore should be avoided if possible. The repair of trepanned holes and weld-probe holes should be planned and inspected carefully.

Repairs can also be made by riveting or bolting, using the procedures given in the standards for riveted or bolted tanks. Leaking rivet seams and rivets can be caulked, riveted, welded, sandblasted, and plastic-coated. The liquid level of the tank must be held below the location of repair until the plastic has dried. When parts or riveted seams are sealed by welding, the rivets and seams should be caulked for approximately 6 inches in both directions from the welding. Defective rivets can also be replaced by tap bolts, especially in the bottom plates where it is impossible to reach the underside of the bottom. All repairs which involve caulking, riveting, bolting, and partial welding should also be reinspected.

When old plate material is removed before patching a corroded area, the remaining opening should have liberally rounded corners. This requirement applies to the shell only, whether the patch is to be flush or lapped. Square-cornered cuts should not be used because of the stress concentration introduced by the sharp corner. Bottom-plate patches normally are lapped plates attached by single-fillet welding surrounding the plate, by tap bolts and caulking, or tap bolts and a gasket. Shell-plate patches also may be lapped plates, if permitted by API Standard 650; they should be fillet-welded from both sides. Alternately, they can be riveted with caulking or bolted with a gasket. Flush patches can be used with butt welding, preferably from both sides. The joint efficiency (ratio of the strength of the joint to the strength of the solid plate) of shell patches that are more than 1 square foot in area should be at least equal to the efficiency of the original joints in the shell ring. Usually, roof patches are made with lapped plates without cutting out the old plate, and can be attached by fillet welding, riveting, or bolting.

If the complete bottom plate must be replaced, it should be done by welding, if possible. The replacement plates can be taken into the tank through a slot cut in the bottom shell course.

When new bottoms are installed through slots, as illustrated in Figure 61, each sketch plate should be welded in place or securely wedged to the upper part of the shell plate before cutting the next slot. This is to prevent the shell from sagging in wide, unsupported areas. At least 3 inches of sand fill should be extended beyond the new bottom so that the shell is supported on the foundation

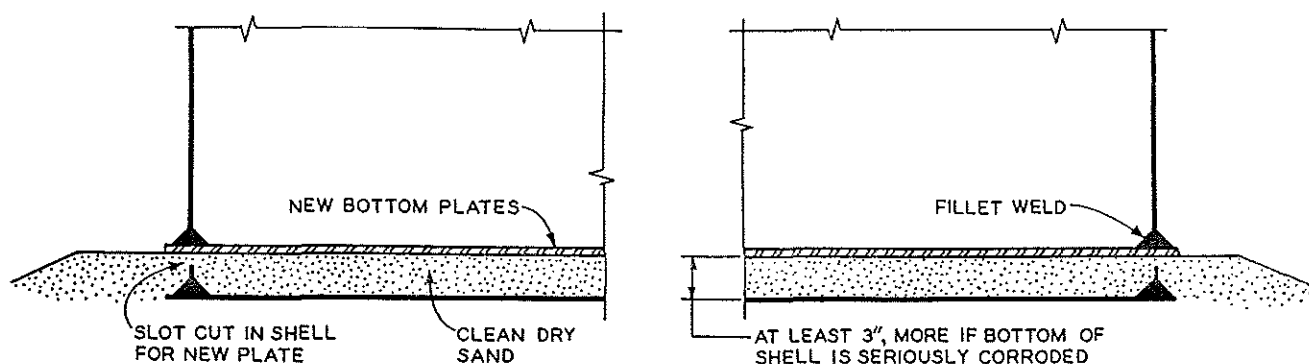


Figure 61—Method of Repairing Tank Bottoms

through the new bottom, thereby transmitting no load to the section of the shell below the new bottom.

If the old bottom has been protected by cathodic means, or if cathodic protection is planned for the new bottom, the old bottom should be completely removed. If it is not removed, the old bottom forms a shield that collects the cathodic current flowing through the ground and prevents cathodic protection of the new bottom. In addition, electrolytic cells develop between the old and new bottom. Experience has shown that the current flow and metal loss will be from the new bottom instead of from the old bottom.

Plastics are valuable corrosion protection for storage tank shells, bottoms, roofs, and pontoons. Combined with fiberglass cloth they provide effective repairs for bottoms, roofs, and pontoons, as well as other low-stress members.

Roof plates can be completely replaced usually in the same manner as when originally constructed.

The need for replacement of all shell plates justifies the replacement of the entire tank.

Any complete replacement of plates should be inspected in accordance with the applicable rules for new tanks.

Cracks in bottom or shell plates should be repaired by chipping, grinding, gouging, or burning the crack out from end to end entirely through the plate before welding. If several cracks occur in one plate, it may be wise to replace the plate completely. Welded repairs of cracks should be inspected carefully, especially at the ends of the welded areas.

### 13.5.3 SPECIAL REPAIR METHODS

When deep pits in tank plates are not closely spaced and extensive, and thus do not affect the strength of the tank, they can be repaired by a number of methods if welding is not practical. Any method that will stop the corrosion and plug the leaks will be satisfactory. Large, scattered pits can be drilled and tapped for a tapered plug. Filling with soft solder may be a suitable method, but it requires scrupulous

cleaning of the metal in and around the pit and sufficient heat to ensure a proper "tinning" and bond to the steel plate. Filling with proprietary air-hardening adhesive-to-steel plastic may be suitable if it will not be affected by the tank's contents. Any other material of a putty-like nature that hardens upon drying should be used only for temporary repairs; such material must be able to tolerate the tank's contents in addition to making a tight bond with the steel plate. In all cases the pits should be cleaned thoroughly, preferably by sandblasting, and then plugged as soon as possible.

Leaks in roofs are commonly repaired by "soft patches" that do not involve cutting, welding, riveting, or bolting of the steel. The soft patches can be made from a variety of materials, including canvas, asbestos, rubber, neoprene, glass cloth, asphalt, and proprietary mastic or plastic sealing materials, the choice depending upon the contents of the tank and service conditions. The patching is applied in much the same manner as similar patching would be applied to the roof of a building. The patches may be applied when the tank is in service, if proper safety practices are followed. Figures 62 and 63 show a patch and a complete coating, respectively.

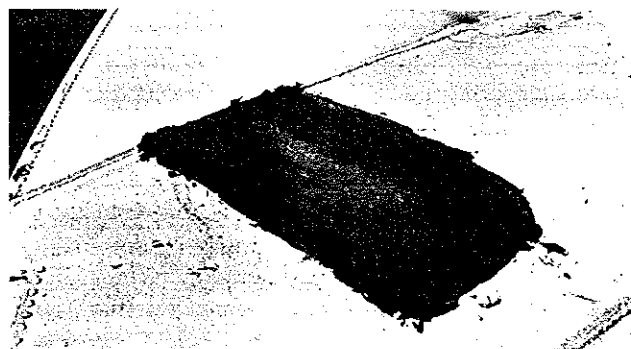


Figure 62—Temporary "Soft Patch" over Leak in Tank

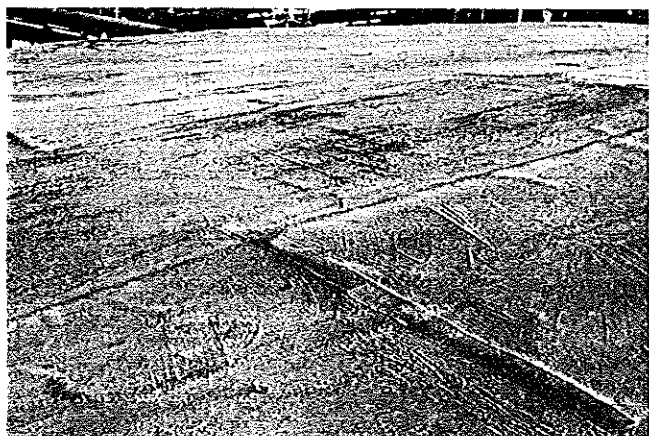


Figure 63—Mastic Roof Coating

Leaks in bottom plates of atmospheric storage tanks can also be repaired temporarily by means of soft patches, such as those used for roofs. In this case, however, any deteriorating effect of the tank's contents on the patching material is most important.

Pads that have washed out or settled under the bottoms of atmospheric storage tanks can be repaired by pumping sand, clay, thin concrete, or similar material under the tank. Material can be pumped through holes cut in the tank bottom. In some cases it may also be necessary to raise the tank with jacks, as shown in Figure 64.

## 13.6 Records and Reports

### 13.6.1 GENERAL

The importance of keeping complete records cannot be overemphasized. Inspection records form the basis of a scheduled maintenance program. With good, complete records, it is usually possible to predict when repairs and replacements will be needed. This helps prevent emergency out-of-service time and also saves time by allowing manpower and materials to be scheduled before a shutdown. Records can also be used as a research file when information is needed for specifications for new tanks.

### 13.6.2 RECORDS

A complete record file should consist of at least three types of records, namely, construction records, field notes, and history cards. Construction records include prints and specifications and any results of material tests and analyses. Field notes are recorded in the field, either on pre-

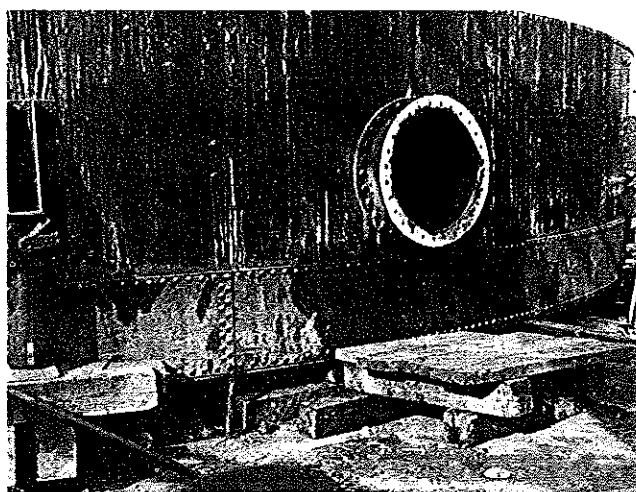


Figure 64—Tank Jacked Up for Repairing Pad

pared forms or in a field notebook. These notes should include all measurements taken, the condition of all parts inspected, and a record of all repairs. A complete description of any unusual conditions with recommendations for correction of design or details which caused the conditions should also be included. History cards or records include all data accumulated on a tank from the time of its construction. All measurements, repairs, replacements, and service changes are recorded in this section. Service conditions such as stored material, temperature, and pressure belong in the history section. These records should include the results of any experiments with coatings and linings. If a tank is settling, a record of settling measurements and a description of any bench marks should be in the history section.

### 13.6.3 REPORTS

Reports recommending repairs should include the location, extent, and reasons for the repairs.

General inspection reports should include metal thickness measurements, conditions found, repairs, any settlement measurements, and recommendations.

Occasionally, special reports covering results of experiments or unusual conditions may be circulated. The results of coating experiments or excessive cracking in welds would fall in this group.

Appendix A includes samples of a typical tank field note record form, history card, and inspection report sheet used to forward information to interested personnel. Any system used should include the basic information shown on these forms.

## **APPENDIX**

### **TYPICAL INSPECTION RECORD AND REPORT FORMS**

The following model report and record forms are supplied as guides for the type of information that should be maintained. Of course, special circumstances may dictate the need for more extensive records.

## TYPICAL FIELD RECORD FORM

PAGE \_\_\_\_\_ OF \_\_\_\_\_  
 BY \_\_\_\_\_  
 DATE \_\_\_\_\_  
 DEPARTMENT \_\_\_\_\_

TANK NO. \_\_\_\_\_  
 LOCATION \_\_\_\_\_ SERVICE \_\_\_\_\_  
 SIZE \_\_\_\_\_ GRAVITY \_\_\_\_\_  
 GRADE \_\_\_\_\_ COIL \_\_\_\_\_

WEST-SOUTH HEAD OR ROOF THICKNESS \_\_\_\_\_  
 CONDITION \_\_\_\_\_  
 ROOF SUPPORTS \_\_\_\_\_  
 ROOF PURLINS \_\_\_\_\_ ANGLE \_\_\_\_\_

| RING | THICKNESS | CONDITION |
|------|-----------|-----------|
| 1    | _____     | _____     |
| 2    | _____     | _____     |
| 3    | _____     | _____     |
| 4    | _____     | _____     |
| 5    | _____     | _____     |
| 6    | _____     | _____     |
| 7    | _____     | _____     |
| 8    | _____     | _____     |

EAST-NORTH HEAD OR BOTTOM THICKNESS \_\_\_\_\_  
 CONDITION \_\_\_\_\_

| VERTICAL |       |       |       |
|----------|-------|-------|-------|
| RING     | TYPE  | RIVET | PITCH |
| 1        | _____ | _____ | _____ |
| 2        | _____ | _____ | _____ |
| 3        | _____ | _____ | _____ |
| 4        | _____ | _____ | _____ |
| 5        | _____ | _____ | _____ |
| 6        | _____ | _____ | _____ |
| 7        | _____ | _____ | _____ |
| 8        | _____ | _____ | _____ |

| CIRCUMFERENTIAL |       |       |       |
|-----------------|-------|-------|-------|
| RING            | TYPE  | RIVET | PITCH |
| 1               | _____ | _____ | _____ |
| 2               | _____ | _____ | _____ |
| 3               | _____ | _____ | _____ |
| 4               | _____ | _____ | _____ |
| 5               | _____ | _____ | _____ |
| 6               | _____ | _____ | _____ |
| 7               | _____ | _____ | _____ |
| 8               | _____ | _____ | _____ |

BUTT STRAPS \_\_\_\_\_  
 BOTTOM TEST PLUGS \_\_\_\_\_

**TYPICAL FIELD RECORD  
FORM**

PAGE \_\_\_\_\_ OF \_\_\_\_\_

BY \_\_\_\_\_

DATE \_\_\_\_\_

DEPARTMENT \_\_\_\_\_

**RECOMMENDATIONS**

ROOF

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SHELL

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BOTTOM

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\_\_\_\_\_  
INSPECTOR\_\_\_\_\_  
DATE

TANK OR PRESSURE VESSEL \_\_\_\_\_  
 SIZE \_\_\_\_\_  
 SERVICE \_\_\_\_\_  
 DRAWING NO. \_\_\_\_\_  
 DEPARTMENT \_\_\_\_\_  
 LOCATION \_\_\_\_\_

LONGITUDINAL JOINT \_\_\_\_\_

ROOF SUPPORTS \_\_\_\_\_

HEAD \_\_\_\_\_

ROOF RAFTERS \_\_\_\_\_

ANGLE \_\_\_\_\_

CIRCUMFERENTIAL JOINT \_\_\_\_\_

INLET \_\_\_\_\_

SAFETY VALVE SIZE \_\_\_\_\_

MAXIMUM WORKING PRESSURE \_\_\_\_\_

SAFETY VALVE SETTING \_\_\_\_\_

TEMPERATURE \_\_\_\_\_

COIL \_\_\_\_\_

ELEVATION \_\_\_\_\_

SUPPORTS \_\_\_\_\_

JACKET \_\_\_\_\_

[illegible]

## TYPICAL TANK REPORT FORM

PAGE \_\_\_\_\_ OF \_\_\_\_\_

BY \_\_\_\_\_  
Mechanical Inspection Department

DATE INSPECTED \_\_\_\_\_

LAST INSPECTION \_\_\_\_\_

TANK NO. \_\_\_\_\_ SERVICE \_\_\_\_\_

SIZE \_\_\_\_\_ MAP LOCATION \_\_\_\_\_

## ROOF

|          | THICKNESS IN 32nds    | CONDITIONS | SUPPORTS              | PURLINS AND ANGLE       |               |                |
|----------|-----------------------|------------|-----------------------|-------------------------|---------------|----------------|
| LOCATION | THICKNESS<br>IN 32nds | CONDITIONS | VERTICAL<br>SEAM TYPE | BUTT-STRAP<br>THICKNESS | RIVET<br>SIZE | RIVET<br>PITCH |
| Bottom   | _____                 | _____      | _____                 | _____                   | _____         | _____          |
| 1st Ring | _____                 | _____      | _____                 | _____                   | _____         | _____          |
| 2nd Ring | _____                 | _____      | _____                 | _____                   | _____         | _____          |
| 3rd Ring | _____                 | _____      | _____                 | _____                   | _____         | _____          |
| 4th Ring | _____                 | _____      | _____                 | _____                   | _____         | _____          |
| 5th Ring | _____                 | _____      | _____                 | _____                   | _____         | _____          |
| 6th Ring | _____                 | _____      | _____                 | _____                   | _____         | _____          |
| 7th Ring | _____                 | _____      | _____                 | _____                   | _____         | _____          |
| 8th Ring | _____                 | _____      | _____                 | _____                   | _____         | _____          |

| LOCATION | CIRCUMFERENTIAL<br>SEAM TYPE | RIVET<br>SIZE | RIVET<br>PITCH | CONDITIONS & RECOMMENDATIONS                                        |
|----------|------------------------------|---------------|----------------|---------------------------------------------------------------------|
| Bottom   | _____                        | _____         | _____          | (For sketches and further information,<br>please use reverse side.) |
| 1st Ring | _____                        | _____         | _____          |                                                                     |
| 2nd Ring | _____                        | _____         | _____          |                                                                     |
| 3rd Ring | _____                        | _____         | _____          |                                                                     |
| 4th Ring | _____                        | _____         | _____          |                                                                     |
| 5th Ring | _____                        | _____         | _____          |                                                                     |
| 6th Ring | _____                        | _____         | _____          |                                                                     |
| 7th Ring | _____                        | _____         | _____          |                                                                     |
| 8th Ring | _____                        | _____         | _____          |                                                                     |

## APPROVAL

This tank is satisfactory for operation at \_\_\_\_\_ height in \_\_\_\_\_ service at \_\_\_\_\_ gravity after repairs recommended by the inspector have been made.

\_\_\_\_\_  
Engineering Department





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