Aboveground Storage Tank Standards: A Tutorial

HEALTH AND ENVIRONMENTAL AFFAIRS DEPARTMENT

API PUBLICATION NO. 327

SEPTEMBER 1994

STEP
Strategies for Today's Environmental Partnership

American Petroleum Institute
1220 L Street, Northwest
Washington, D.C. 20005

Strategies for Today's
Environmental Partnership

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- To work with others to resolve problems created by handling and disposal of hazardous substances from our operations.
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- To promote these principles and practices by sharing experiences and offering assistance to others who produce, handle, use, transport or dispose of similar raw materials, petroleum products and wastes.

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ACKNOWLEDGEMENTS

This project was undertaken by the American Petroleum Institute (API) through the combined efforts of consultants, company representatives, and API staff. Will Carter of Chevron Oil Company, in conjunction with the API Storage Tank Task Force, developed the concept of the document. Rich Basile of Exxon, Phil Smith of Texaco, Bruce Roberts of Aramco, and Rick Nichols of Pennzoil made substantial contributions to the technical details. Dee Gavora of API's Health and Environmental Affairs Department served as Project Officer. Dana Marinacci, a graduate student in public policy at Duke University, assisted in technical editing and production of this report. The API Refining Department and Office of General Counsel provided essential review of the technical information to facilitate completion of this document.

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PREFACE

The American Petroleum Institute (API) sponsored the preparation of this document, "Aboveground Storage Tank Standards: A Tutorial," which presents procedures and examples to aid in understanding and complying with API's Recommended Practices (RPs), Standards (STDs), and Specifications (SPECs) regarding the prevention of leaks caused by bottom or shell corrosion, brittle fracture, and excessive settlement. It also shows how the API inspection and maintenance requirements influence the initial design of tanks. This tutorial is not meant to be used by itself; rather it is meant to be used as an aid in understanding the relevant RPs, STDs, and SPECs and to be used in conjunction with those documents.

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1.0 INTRODUCTION AND SCOPE

1.1 Introduction

This document is published to help owner/operators of aboveground storage tanks (ASTs) maintain ASTs in an environmentally safe manner.

API maintains several comprehensive documents that address the design, fabrication, operation, inspection, and maintenance of ASTs. Based on the combined industry experience of tank designers, fabricators and owners, the API documents provide guidelines designed to minimize the risk of an environmental hazard caused by spills or leaks.

This tutorial presents a set of procedures and examples to aid in understanding and complying with API Recommended Practices (RPs), Specifications (SPECs) and Standards (STDs).

1.2 Scope

The procedures contained in this tutorial address the prevention of leaks or catastrophic loss caused by corrosion of the tank bottom or shell, brittle fracture, and excessive settlement. And, most importantly, they show how the API inspection and maintenance documents influence the design of new or proposed tanks.

This document is applicable to ASTs fabricated and/or maintained per the following standards:

- API SPEC 12B: Bolted Tanks for Storage of Production Liquids;
- API SPEC 12D: Field Welded Tanks for Storage of Production Liquids;
- API SPEC 12F: Shop Welded Tanks for Storage of Production Liquids;
- API RP 12R1: Setting, Maintenance, Operation, and Repair of Tanks in Production Service;
- API STD 650: Welded Steel Tanks for Oil Storage;
- API RP 651: Cathodic Protection of Aboveground Storage Tanks;
- API RP 652: Lining of Aboveground Petroleum Storage Tank Bottoms;
- API STD 653: Tank Inspection, Repair, Alteration, and Reconstruction.

Application of the principles discussed in this tutorial to ASTs constructed to differing design criteria should be based on sound engineering judgements. This tutorial does not attempt to address additional rules and requirements that may be imposed by individual jurisdictions or states.

2.0 SUMMARY OF PROCEDURES

Figures 2.1, 2.2, and 2.3 are logic diagrams that provide a picture of the process used to minimize the risk of bottom or shell leaks from a proposed or existing tank. The discussion below briefly summarizes each diagram.

2.1 Proposed Tanks

Figure 2.1 shows that the first decision relates to whether the tank is proposed or existing. While the evaluation steps for a proposed or existing tank may be similar or in some cases identical, the results for a proposed tank provide options that influence design and construction decisions. Results associated with existing tanks may lead to repairs or a change of service conditions.

If the tank is proposed, then how does one comply with the API in-service AST inspection STD 653 and RP 12R1? (Note: These two documents will be referred to collectively as the API Standard). The logic diagram shows that the API Standard does influence the proposed design, especially in the important area of bottom selection.

If the tank is proposed, then one proceeds along the left side of Figure 2.1. After compiling basic data, the major benefit of the procedure is to provide tank bottom design options. This is an important step. If the owner/operator expects a reasonable onstream time, then the influence of cathodic protection, leak detection, linings, etc., on inspection frequency must be explored.

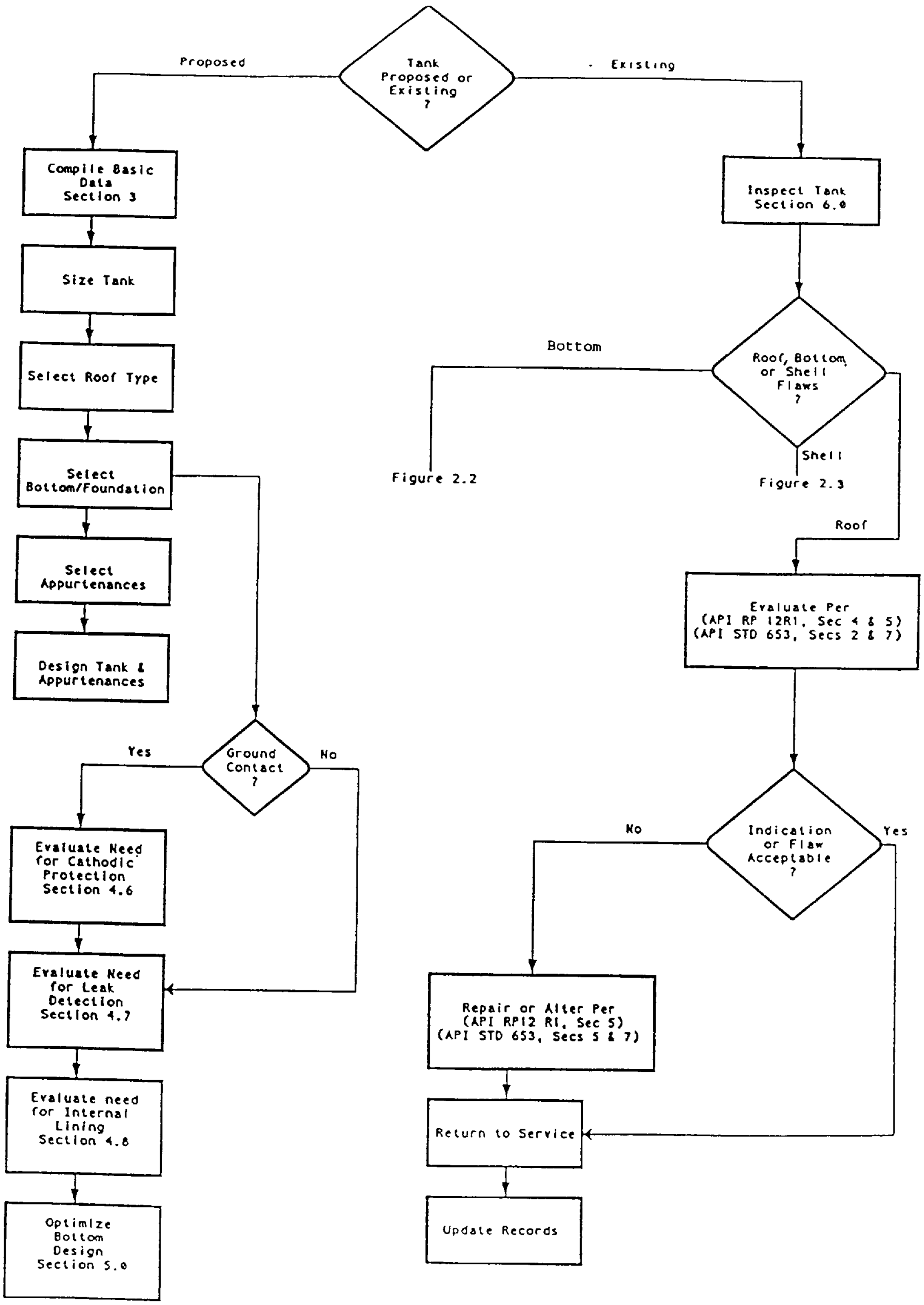
Tank bottom design is based on standards and engineering and economic data. The last box on Figure 2.1 provides a method for selecting a bottom design when several configurations satisfy the API Standard.

2.2 Existing Tanks

The right side of Figure 2.1 shows that the evaluation process for existing tanks is separated into three paths. Tank Bottom and Shell are the two paths which are addressed in this tutorial, and are shown in Figures 2.2 and 2.3, respectively.

The decision path for evaluation of a tank roof is beyond the scope of this tutorial. However, Figure 2.1 shows that existing tank roofs may be evaluated per the methods in the API Standard and repaired, altered, or returned to service.

FIGURE 2.1: LOGIC DIAGRAM FOR TANK DESIGN & EVALUATION



2.3 Tank Bottom

Figure 2.2 shows the process for evaluating an existing tank bottom. The first decision is to identify concerns associated with either settlement, corrosion, or both. This identification is determined by a tank inspection and evaluation of the inspection data.

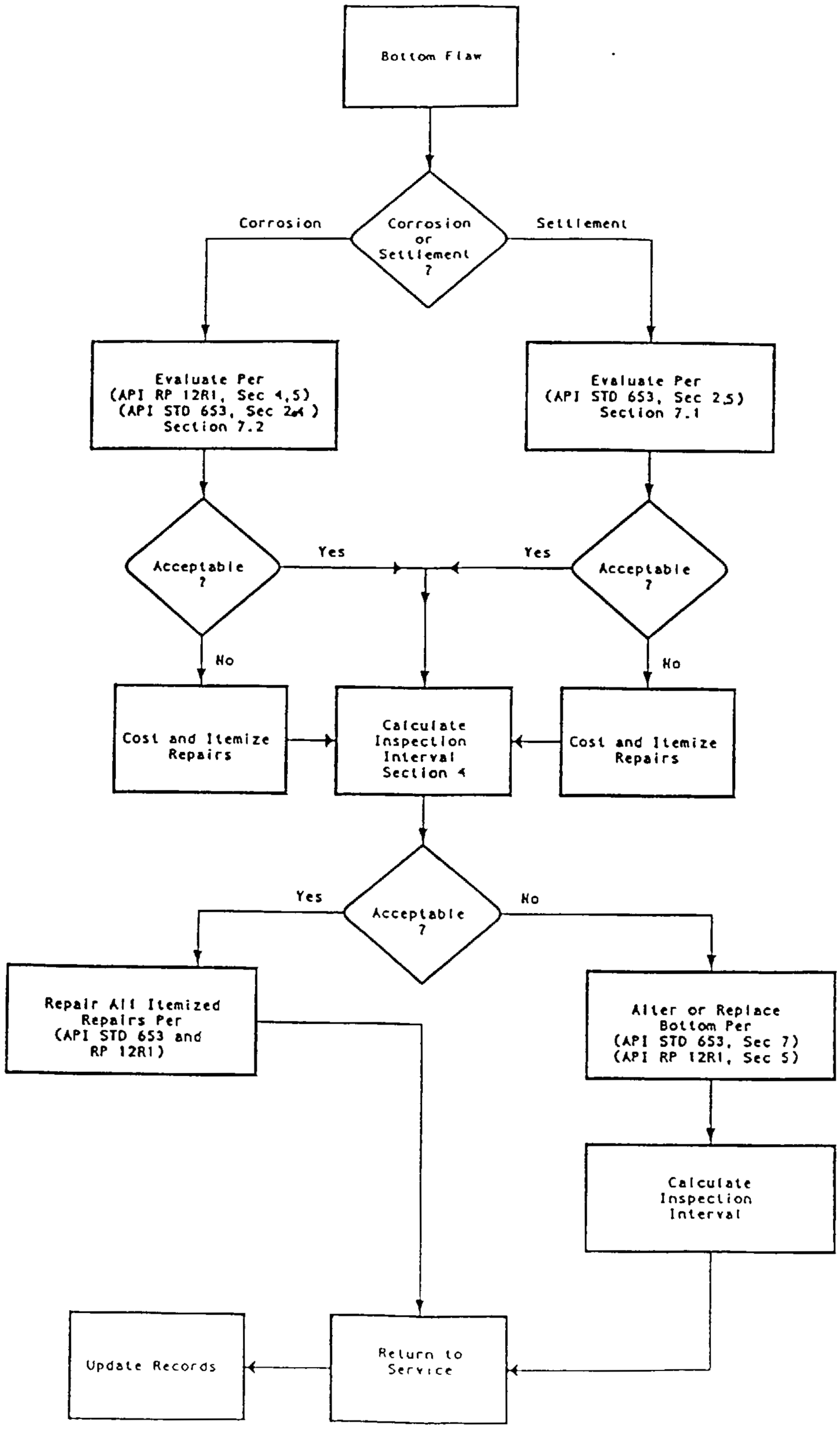
If a settlement problem is identified, then it should be evaluated as shown in Section 6.1. If found unacceptable, the problem should be added to the list of repair items.

The left side of Figure 2.2 shows the process for evaluating bottom corrosion. The referenced sections of API RP 12R1 and API STD 653, and Section 6.2 of this document provide guidance for this evaluation. When the damaged areas are found to be unacceptable, they should be added to the list of repair items.

After evaluating all the inspection data, the internal inspection interval must be calculated as described in Section 6.2, (assuming that all repairs are performed). Provided the interval is acceptable, the bottom repairs may proceed.

However, if the interval is not acceptable, the bottom must be altered, repaired, or replaced before the tank is returned to service. The procedure to evaluate these options is explained in Section 4 and includes examples.

FIGURE 2.2: LOGIC DIAGRAM FOR BOTTOM EVALUATION



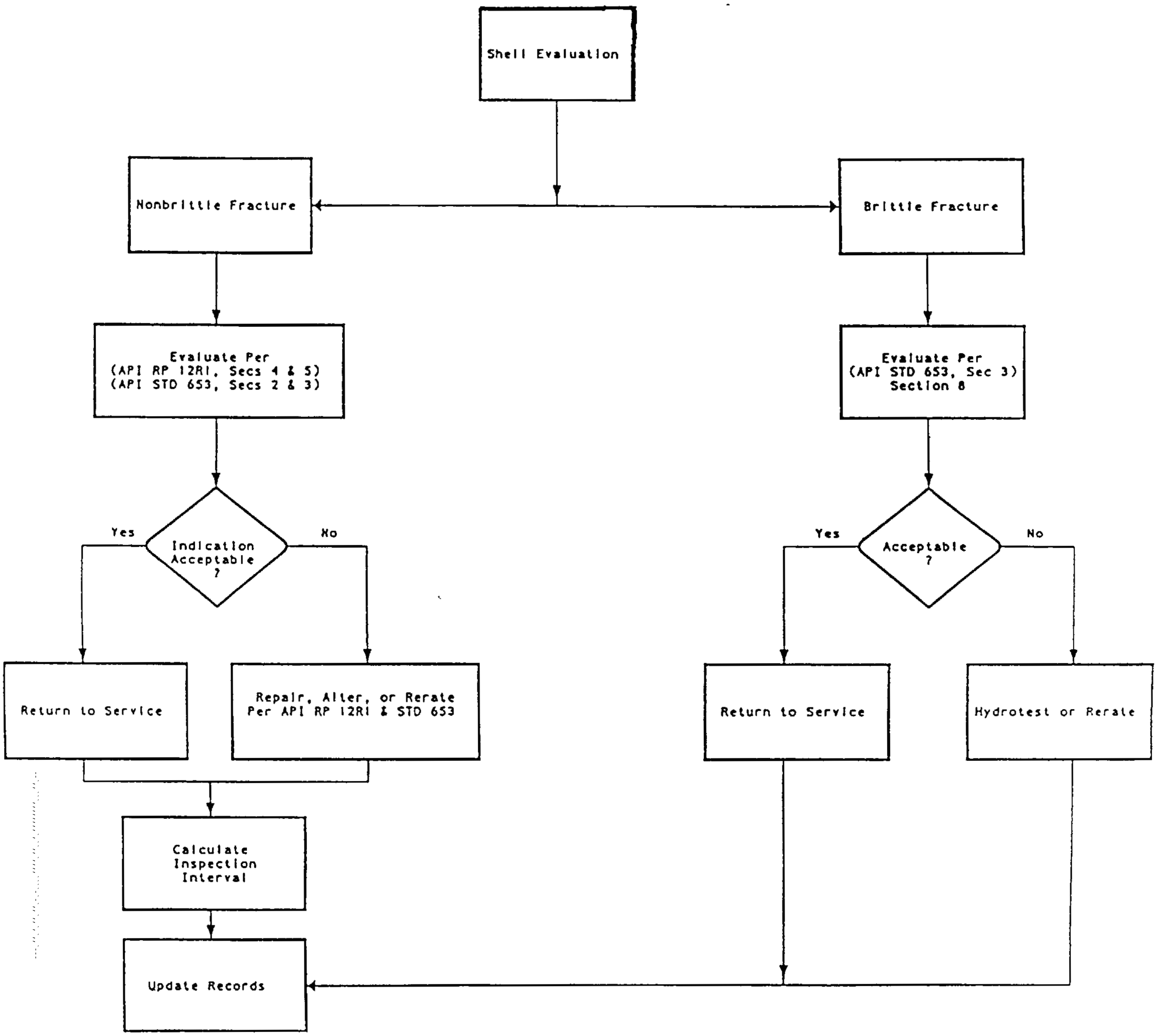
2.4 Tank Shell Evaluation

Figure 2.3 shows two paths for evaluating a tank shell. The right path is for brittle fracture considerations and should be done during the initial evaluation of a tank or when there is a change of service.

Shell evaluations that are not related to brittle fracture are typically related to corrosion/erosion, shell distortions and/or shell settlement, and these evaluation are shown on the left path. Section 8 of this tutorial identifies the paragraphs in the API Standard associated with these evaluations and illustrates how to apply the requirements.

The evaluation process for an existing tank is the basis for determining acceptability for continued service. If the results are unacceptable, then the tank must be repaired, altered, or considered for a change of service.

FIGURE 2.3: LOGIC DIAGRAM FOR SHELL EVALUATIONS



3.0 BASIC DATA REQUIREMENTS

Before using the API documents listed in Section 1.2, the reader should assemble certain basic data. These data are required before decisions can be made on the most appropriate aboveground storage tank for a given situation. The data listed in the left column below are considered essential, and additional discussion of each requirement can be found in the documents listed in the right column.

FIGURE 3.0 - HIGH PRIORITY DATA

DATA	DOCUMENTS
• Foundation and Soil Condition	RP 12R1, Section 2 STD 650, Appendix B RP 651, Section 3 STD 653, Section 2
• Corrosion Data	SPECs 12D & 12F, Section 5 RP 12R1, Sections 2, 4 & 5 STD 650, Section 3 RP 651, Sections 2, 3 & 5 RP 652, Section 3 STD 653, Sections 2 & 4
• Operating Data which relate to above items	RP 12R1, Sections 2 & 4 STD 650, Appendix M RP 651, Sections 2 & 3 RP 652, Section 4 STD 653, Sections 2, 3, 7 & 10

4.0 BOTTOM SELECTION

This section describes procedures and considerations for selecting a tank-bottom corrosion protection design that conforms to the API Standards.

The necessary site and subsurface investigations are assumed to have been completed, and tank size, corrosion, and type of bottom, (that is cone-up, flat, cone-down, etc.) questions have been resolved.

Selecting the appropriate tank bottom corrosion protection system depends on the type of soil under the tank, expected or actual internal and external corrosion rates, location of the tank field, maintenance program, and design life of the tank.

Requirements for internal inspections have the greatest affect on tank bottom design. Internal inspection can be done only if the tank is taken out of service and entered. Owner/operators work to minimize out-of-service inspections because they are time-consuming, expensive and may generate residual material and emissions.

4.1 Tanks built to API Standard 650 Specifications

API STD 653 links out-of-service internal inspections to the thickness of the tank components including bottom plates. Section 2.4.7.3 of API STD 653 states that the minimum remaining thickness (MRT) of the bottom plates must be equal to or greater than the appropriate thickness shown in API STD 653 Table 4.1 at the end of the in-service period of operation.

The following equations are included in API STD 653 and are considered to be an acceptable method for calculating MRT:

$$\mathbf{MRT_1 = T_o - GC_a - StP_a - UP_m - (StP_r + UP_r + GC_r)\ O_r}$$

$$\mathbf{MRT_2 = T_o - GC_a - StP_m - UP_a - (StP_r + UP_r + GC_r)\ O_r}$$

Where:

MRT_1 = minimum remaining thickness due to average internal pitting and maximum external pitting, in inches.
MRT_2 = minimum remaining thickness due to maximum internal pitting and average external pitting, in inches.
T_o = original plate thickness, in inches.
GC_a = average depth of generally corroded area, in inches.
StP_a = average depth of internal pitting, in inches.
StP_m = maximum depth of internal pitting, in inches.
UP_m = maximum depth of underside pitting, in inches.

UP_a = average depth of underside pitting, in inches.
StP_r = maximum internal pitting rate, in inches per year; StP_r = 0 if the tank bottom is internally lined (see API RP 652).
UP_r = maximum underside pitting rate, in inches per year; UP_r = 0 if tank bottom is cathodically protected (see API RP 651).
GC_r = maximum rate of general corrosion, in inches per year.
O_r = anticipated in-service period of operation, in years.

4.2 API 12 Series Production Tanks

Production tanks are usually much smaller than API Standard 650 tanks and their operating conditions and objectives are often substantially different than those used in refining, marketing, and transportation operations. These and other unique characteristics are reflected in API RP 12R1.

API RP 12R1 requires two types of scheduled internal examinations, the scheduled Internal Condition Examination (conducted by appropriate field personnel) and the scheduled Internal Inspection (conducted by a qualified inspector).

At a minimum, a scheduled Internal Condition Examination should be made for the following events:

- When a tank is cleaned for normal operational requirements;
- When there is a change in tank location;
- When the service is changed more than five years after an Internal Inspection; or
- When the tank is entered for any type of maintenance or modification.

Scheduled Internal Inspections should be based on the corrosion rate life of the tank as given by:

$$\textbf{Corrosion Rate Life (years)} = \frac{(t_{current} - t_{minimum})}{\textbf{corrosion rate (inches/year)}}$$

Where $t_{current}$ is the measured thickness of the bottom plate and where $t_{minimum}$, for the Critical Annular Ring area, is 0.50 times $t_{minimum}$ of the shell or a minimum of 0.062 inch.

For small production tanks, the calculation is based on the structural consideration of the annular ring.

At a minimum, inspections should occur at the beginning of the last quarter of the predicted life when a minimum required plate thickness is still in place.

4.3 Case Studies

Three cases are shown below, with basic design data provided for each. These cases are used as the basis for the examples in this section.

Case 1 - Basic Design Data for 150,000 BARREL API STD 650 Tank

A 150,000 barrel API STD 650 tank is in the design stage. The design data are:

Capacity	150,000 barrels
Soil Condition	Firm, little settlement and good drainage
Stored Product	Petroleum crude
Frequency of Internal Inspection	10 years
General Corrosion	3 mpy
Internal Bottom Pitting	20 mpy
External Bottom Pitting	25 mpy bare steel 3 mpy on concrete slab 3 mpy if cathodically protected
Design Life	40 years
Size	Height 48 feet, Diameter 150 feet
Bottom Plates	0.25 inch

Case 2 - Basic Design Data for 10,000 BARREL Gasoline Storage Tank

A 10,000 barrel gasoline storage tank is proposed. The underside corrosion is based on replacing the native soil below the tank. The following design information is available:

Capacity	10,000 barrels
Soil Condition	Good drainage, moderate settlement
Stored Product	Gasoline
Frequency of Internal Inspection	10 years
General Corrosion	4 mils per year (mpy)
Internal Bottom Pitting	6 mpy
External Bottom Pitting	9 mpy
Design Life	40 years
Size	Height 24 feet, Diameter 55 feet
Bottom Plates	0.25 inch

Case 3 - Basic Design Data for 500 BARREL Production Fluid Tank

A 500 barrel production fluid tank is set up at a new site. The tank is internally lined and placed on a crushed stone foundation. The design data are:

Capacity	500 barrels
Soil Condition	Crushed stone with retainer ring over loose fine sand
Stored Product	Production fluids
Frequency of Internal Inspection	Per API RP 12R1
General Corrosion	0
Internal Bottom Pitting	5 mpy
External Bottom Pitting	0
Design Life	40 years
Size	Height 16 feet, Diameter 15 feet, 6 inches
Bottom Plates	0.25 inch
Minimum for Shell	0.036

4.4 Ground Contact

Tank bottoms in contact with the ground will experience some degree of corrosion even when the native material is removed (see RP 651, Section 3). Paragraph 4.4.2.2 of API STD 653 states that when there is no means for detection and containment of bottom leaks, MRT must be equal to or greater than 0.10 inch.

Example 4.1 illustrates this requirement for the 150,000 barrel tank in Case 2. The example assumes that the tank bottom is in contact with the ground. It is evident in the example that some form of external, and perhaps internal, corrosion protection will be needed to satisfy API STD 653 requirements.

Example 4.1 - Ground/Bottom Contact - 150,000 Barrel Tank

Consider the 150,000 barrel tank in Case 1. Using API STD 653 requirements, determine the MRT at the end of the initial 10 year period assuming no corrosion protection. Quantities for the MRT equations are:

T_o	= 0.25 inch.
GC_a	= 0.0 for a new tank.
StP_a & StP_m	= 0.0 for a new tank.
UP_a & UP_m	= 0.0 for a new tank.
StP_r	= 0.020 inch per year.
UP_r	= 0.025 inch per year.
GC_r	= 0.003 inch per year.
O_r	= 10 years.

$$MRT_1 = T_o - GC_a - StP_a - UP_m - (StP_r + UP_r + GC_r)\ O_r$$

$$MRT_2 = T_o - GC_a - StP_m - UP_a - (StP_r + UP_r + GC_r)\ O_r$$

Substituting into the equations yields:

$$MRT_1 = MRT_2 = 0.25 - 0 - 0 - 0 - (0.020 + 0.025 + 0.003)\ 10$$

$$MRT_1 = MRT_2 = -0.23 \text{ inch}$$

The results of Example 4.1 indicate that a hole will be produced in the bottom before the next scheduled inspection at the end of 10 years; therefore, additional protection must be provided. Using a value of 0.10 inches for MRT, the equation can be solved for O_r — or the anticipated in-service period of operation. In fact, if the tank is placed in service without corrosion protection, API STD 653 would require an out-of-service internal inspection in about 3 years.

Example 4.2 applies paragraph 4.4.2.2 of API STD 653 to the 10,000 barrel gasoline tank in Case 1.

Example 4.2 - Ground/Bottom Contact - 10,000 Barrel Gasoline Tank

Given the tank in Case 2, determine the MRT at the end of an initial 10 year period assuming no corrosion protection. Quantities for the MRT equations are:

$\mathbf{T_o}$	= 0.25 inch.
$\mathbf{GC_a}$	= 0.0 for a new tank.
$\mathbf{StP_a}$ **&** $\mathbf{StP_m}$	= 0.0 for a new tank.
$\mathbf{UP_a}$ **&** $\mathbf{UP_m}$	= 0.0 for a new tank.
$\mathbf{StP_r}$	= 0.006 inch per year.
$\mathbf{UP_r}$	= 0.009 inch per year.
$\mathbf{GC_r}$	= 0.004 inch per year.
$\mathbf{O_r}$	= 10 years.

$$\mathbf{MRT_1 = T_o - GC_a - StP_a - UP_m - (StP_r + UP_r + GC_r)\, O_r}$$

$$\mathbf{MRT_2 = T_o - GC_a - StP_m - UP_a - (StP_r + UP_r + GC_r)\, O_r}$$

Substituting into the equations yields:

$$MRT_1 = MRT_2 = 0.25 - 0 - 0 - 0 - (0.006 + 0.009 + 0.004)\ 10$$

$$MRT_1 = MRT_2 = 0.06 \text{ inch}$$

API STD 653 requires a minimum thickness of 0.10 inch; therefore, additional corrosion protection must be provided in order to maintain the 10 year inspection interval.

An anticipated in-service-period of 7.9 years results from the MRT value of 0.10 inch.

4.5 Production Tanks

Example 4.3 applies the criteria of RP 12R1 to the proposed tank in Case 3.

While the example shows a calculated out-of-service internal inspection interval of 28 years, it is highly likely that an Internal Conditional Examination will be triggered by one of the four items listed in paragraph 4.2 before the time period has elapsed.

It is important to note that many production tanks will not be at the same location for the period of time that is calculated for the internal inspection interval. Tanks that are relocated should have an Internal Condition Examination and, if warranted, a Condition Inspection when relocated.

Example 4.3 - Ground/Bottom Contact - 500 Barrel Production Tank

Determine the out-of-service internal inspection interval for Case 3, using the procedure given in API 12R1. The corrosion rate is 0.005 inches per year.

Determine $t_{minimum}$ where $t_{minimum}$ is based on the structural considerations of the annular ring.

Annular Ring

For the critical annular ring area, $t_{minimum}$ is 0.5 times $t_{minimum}$ of the shell (0.036 inch) or a minimum of 0.062 inches.

Or, $t_{minimum}$ is the larger of 0.5 (0.036) = 0.018 inches or 0.062 inches

Therefore $t_{minimum}(a)$ = 0.062 inch.

$$\textbf{Corrosion Life (years)} = \frac{(t_{current\ thickness} - t_{minimum})}{\textbf{corrosion rate (inches/year)}}$$

Corrosion $Life_a$ = (0.25 - 0.062)/(0.005) = 37.6 years.

Last quarter begins 0.75 (37.6 years) = 28.2 years.

Therefore, the calculated interval is 28 years.

4.6 Cathodic Protection

Paragraph 4.4.2.2 of API STD 653 does not allow a reduction in MRT if the tank bottom is cathodically protected. However, Section 2.4.7.1 of the standard will allow a value of zero for external pitting if the tank bottom is protected by a properly designed and maintained cathodic protection system.

Example 4.4 shows the calculations for the 150,000 barrel tank (Case 1) assuming the bottom is cathodically protected.

Example 4.4 - Cathodically Protected Bottom

Using the data given in Case 1, determine the MRT at end of an initial 10 year period assuming the bottom is cathodically protected. Quantities for the MRT calculations are:

$\mathbf{T_o}$ = 0.25 inch.
$\mathbf{GC_a}$ = 0.0 for a new tank.
$\mathbf{StP_a}$ **&** $\mathbf{StP_m}$ = 0.0 for a new tank.
$\mathbf{UP_a}$ **&** $\mathbf{UP_m}$ = 0.0 for a new tank.
$\mathbf{StP_r}$ = 0.020 inch per year.
$\mathbf{UP_r}$ = 0.0 inch per year.
$\mathbf{GC_r}$ = 0.003 inch per year.
$\mathbf{O_r}$ = 10 years.

$$\mathbf{MRT_1 = T_o - GC_a - StP_a - UP_m - (StP_r + UP_r + GC_r)\, O_r}$$

$$\mathbf{MRT_2 = T_o - GC_a - StP_m - UP_a - (StP_r + UP_r + GC_r)\, O_r}$$

Substituting into the equations yields:

$$MRT_1 = MRT_2 = 0.25 - 0 - 0 - 0 - (0.020 + 0.0 + 0.003)\ 10$$

$$MRT_1 = MRT_2 = 0.02 \text{ inch}$$

Additional protection is needed in order to prevent leaks before the next shutdown. The example can also be worked using a nominal external pitting rate of 0.001 inches per year. Using this nominal rate will provide a more conservative estimate for MRT. This tutorial does not work through the example for cathodic protection on the tank in Case 2. The reader is encouraged to evaluate this option on their own. (Hint: To be conservative, set the external pitting rate to a nominal value. What answer did you get? Using a UP_r = 0.001, MRT_1 = MRT_2 = 0.14 inch.)

4.7 Leak Detection/Containment System

API STD 653 allows a reduction in the MRT if a system to detect and/or contain bottom leaks is installed. With such a system the MRT must be greater than or equal to 0.05 inch. Example 4.5 applies the criterion to the 150,000 barrel tank (Case 1).

Example 4.5 - Leak Detection/Containment System

Using the data given in Case 1, determine the MRT at the end of an initial 10 year period assuming a system to detect and contain bottom leaks is installed. The system consists of a concrete slab installed over an impermeable membrane per API 650 to gather and channel leaks. Quantities for the MRT equations are:

$\mathbf{T_o}$ = 0.25 inch.
$\mathbf{GC_a}$ = 0.0 for a new tank.
$\mathbf{StP_a}$ & $\mathbf{StP_m}$ = 0.0 for a new tank.
$\mathbf{UP_a}$ & $\mathbf{UP_m}$ = 0.0 for a new tank.
$\mathbf{StP_r}$ = 0.020 inch per year.
$\mathbf{UP_r}$ = 0.003 inch per year.
$\mathbf{GC_r}$ = 0.003 inch per year.
$\mathbf{O_r}$ = 10 years.

$$\mathbf{MRT_1 = T_o - GC_a - StP_a - UP_m - (StP_r + UP_r + GC_r)\, O_r}$$

$$\mathbf{MRT_2 = T_o - GC_a - StP_m - UP_a - (StP_r + UP_r + GC_r)\, O_r}$$

Substituting into the equations yields:

$$MRT_1 = MRT_2 = 0.25 - 0 - 0 - 0 - (0.020 + 0.003 + 0.003)\ 10$$

$$MRT_1 = MRT_2 = -0.01 \text{ inch}$$

The results are less than 0.05 inches and indicate that the bottom is not sufficiently protected against corrosion. Additional protection must be provided.

Example 4.6 investigates a leak detection system for the 10,000 barrel tank in Case 2. The results show that a simple leak detection and containment system consisting of an impervious barrier below the tank bottom, sloped so that leaks are channeled to the tank perimeter, will satisfy API STD 653 requirements.

Example 4.6 - Leak Detection/Containment System

For the tank proposed in Case 2, determine the MRT at the end of an initial 10 year period assuming a leak detection/containment system is installed. The quantities for the MRT equations are:

$\mathbf{T_o}$	= 0.25 inch.
$\mathbf{GC_a}$	= 0.0 for a new tank.
$\mathbf{StP_a}$ & $\mathbf{StP_m}$	= 0.0 for a new tank.
$\mathbf{UP_a}$ & $\mathbf{UP_m}$	= 0.0 for a new tank.
$\mathbf{StP_r}$	= 0.006 inch per year.
$\mathbf{UP_r}$	= 0.009 inch per year.
$\mathbf{GC_r}$	= 0.004 inch per year.
$\mathbf{O_r}$	= 10 years.

Since the leak detection/containment system is installed below the prepared foundation material, the corrosion rates do not change.

$$\mathbf{MRT_1 = T_o - GC_a - StP_a - UP_m - (StP_r + UP_r + GC_r)\ O_r}$$

$$\mathbf{MRT_2 = T_o - GC_a - StP_m - UP_a - (StP_r + UP_r + GC_r)\ O_r}$$

Substituting into the equation yields:

$$MRT_1 = MRT_2 = 0.25 - 0 - 0 - 0 - (0.006 + 0.009 + 0.004)\ 10$$

$$MRT_1 = MRT_2 = 0.06 \text{ inch}$$

This value is greater than 0.05 inch. Therefore, the tank may be operated for the 10 year period without a scheduled out-of-service internal inspection if a leak detection/containment system is installed.

4.8 Tank Bottom Lining

API RP 652 contains recommendations for internal lining of tank bottoms. API STD 653 sets the tank bottom internal corrosion and pitting rate to zero if the bottom is internally lined with a thick film reinforced lining greater than 0.05 inches (in accordance with API RP 652). Examples 4.7 and 4.8 show the impact of a bottom lining on the two tanks in Cases 1 and 2.

Example 4.7 - Internal Bottom Lining

For the tank proposed in Case 2, determine the MRT at the end of an initial 10 year period assuming a suitable lining is applied to the interior of the bottom. The quantities in the equation are:

$\mathbf{T_o}$	= 0.25 inch
$\mathbf{GC_a}$	= 0.0 for a new tank.
$\mathbf{StP_a}$ & $\mathbf{StP_m}$	= 0.0 for a new tank.
$\mathbf{UP_a}$ & $\mathbf{UP_m}$	= 0.0 for a new tank.
$\mathbf{StP_r}$	= 0.000 inch per year.
$\mathbf{UP_r}$	= 0.009 inch per year.
$\mathbf{GC_r}$	= 0.004 inch per year.
$\mathbf{O_r}$	= 10 years.

Since the leak detection/containment system is installed below the prepared foundation material, the corrosion rates do not change.

$$\mathbf{MRT_1 = T_o - GC_a - StP_a - UP_m - (StP_r + UP_r + GC_r)\ O_r}$$

$$\mathbf{MRT_2 = T_o - GC_a - StP_m - UP_a - (StP_r + UP_r + GC_r)\ O_r}$$

Substituting into the equations yields:

$$MRT_1 = MRT_2 = 0.25 - 0 - 0 - 0 - (0.000 + 0.009 + 0.004)\ 10$$

$$MRT_1 = MRT_2 = 0.12 \text{ inch}$$

This value is greater than the 0.10 inch requirement of API STD 653. Therefore, the tank may be operated for the 10 year period without a scheduled out-of-service internal inspection.

The tank in this example satisfies the API STD 653 MRT requirement of 0.10 inch if the bottom is internally lined. Both an internally lined bottom or a cathodically protected bottom will provide adequate bottom corrosion protection. The selection of an internal liner or cathodic protection system should be based on an economic analysis.

An internal lining is insufficient corrosion protection to satisfy API STD 653 for the 150,000 barrel tank in Case 1. Some form of corrosion protection for both the exterior and interior is needed. Example 4.8 contains calculations for the 150,000 barrel tank, assuming there is adequate internal lining and external cathodic protection. API STD 653 requires that the MRT be at least equal to 0.10 inch for this combination. The calculations in Example 4.8 show that an internally lined and cathodically protected tank bottom will satisfy API STD 653 criteria. An internally lined tank bottom on a concrete leak detection slab (with the corrosion rate assumed in these examples) will also satisfy the criteria. Section 5 suggests a procedure for selecting the most appropriate of the two protection systems.

Example 4.8 - Internal Bottom Lining and Cathodic Protection

Using the data given in Case 1, determine the MRT at the end of the initial 10 year period assuming a corrosion protection system consisting of an internal bottom lining and a cathodic protection system. With both systems in place, API STD 653 allows the internal and external pitting rates to be set to zero. To be conservative and to account for possible degradation of the internal liner system, an internal pitting rate of 0.003 inch per year was assumed.

T_o = 0.25 inch
GC_a = 0.0 for a new tank.
StP_m = 0.0 for a new tank.
UP_m = 0.0 for a new tank.
StP_r = 0.003 inch per year, nominal rate is assumed (see example 4.4).
UP_r = 0.0 inch per year, nominal rate is assumed (see example 4.4).
GC_r = 0.0 inch per year.
O_r = 10 years.

$$\mathbf{MRT = T_o - GC_a - StP_m - UP_m - (StP_r + UP_r + GC_r)\,O_r}$$

Substituting into the equation yields:

$$MRT = 0.25 - 0 - 0 - 0 - (0.003 + 0.0 + 0.0)\ 10$$

$$MRT = 0.22 \text{ inch}$$

The calculated MRT is greater than 0.10 inch; therefore, this combination of external and internal corrosion protection satisfies API STD 653 requirements.

Although API STD 653 allows the external and internal pitting rates to be set to zero when external and internal protection are used, the use of nominal values provides a more conservative result. Nominal values can be based on operating experience or taken from other sources deemed suitable.

5.0 INSPECTION

The primary protection against failure of a properly designed and maintained tank is inspection. API STD 653 and RP 12R1 require several types of inspections and inspection frequencies to insure tank integrity and to provide early detection of potential hazards.

Figure 5.1 summarizes inspections and examinations required by API STD 653. Figure 5.2 summarizes the inspections required by API RP 12R1.

FIGURE 5.1
API STD 653
REQUIRED INSPECTIONS

Type	Frequency	Coverage
Routine In-service	At least monthly	Visual check for leaks, shell distortions, foundation problems, paint/insulation conditions, and appurtenances
Formal In-service	At least every 5 years or at 1/4 corrosion-rate life	Detailed inspection of complete tank exterior the results of which are reviewed by a certified inspector
Out-of-service	At least every 20 years but before bottom thickness is less than 0.10" in a normal bottom or before thickness is less than 0.05" in a bottom with leak detection and containment	Visual inspection of exterior and interior by a certified inspector and detailed inspection of exterior and interior the results of which are reviewed by a certified inspector

FIGURE 5.2
API RP 12R1
REQUIRED INSPECTIONS

Scheduled Type	Internal Tank Examination/Inspection Schedule Frequency	By Whom
Condition Examination	When a tank is: 1. Cleaned for normal operations 2. Transferred to a new location 3. Changed in service more than 5 years after an inspection 4. Entered for any type of maintenance or modification	Competent person or qualified inspector
Condition Inspection	At end of 3/4 of corrosion rate life	Qualified inspector

Scheduled Type	External Tank Examination/Inspection Schedule Frequency	By Whom
Routine operational examinations	At least once a month	Field personnel, technicians
Condition examination	Once a year	Competent person or qualified inspector
Condition inspection	As determined from corrosion rate but not more than 15 years after construction	Qualified inspector

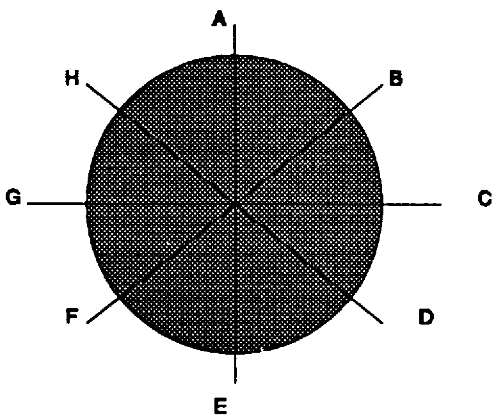
In addition to the scheduled inspections listed above, production tanks are visually inspected on a regular basis. Such unscheduled visual inspections can lead to a condition inspection (see RP 12R1 Page 13 for details).

6.0 BOTTOM FLAWS

6.1 Bottom Settlement

Settlement, if left unchecked, will cause excessive strain on the tank bottom and shell plates and can potentially cause ruptures. API RP 12R1 states that excessive settlement must be corrected. Appendix B of API STD 653 provides specific details regarding settlement evaluation and limits for tanks built to API STD 650. The API STD 653 settlement calculation procedure is simple and easy to perform. It conservatively estimates when foundation corrections must be made or tanks releveled as shown below in Figure 6.1 and explained in Example 6.1. If foundation correction or releveling is required, API STD 653 allows the use of detailed stress analysis to verify the acceptability of the existing settlement.

FIGURE 6.1



Diameter = 47 feet
Height = 48 feet

Tank Settlement Calculation

Location	A	B	C	D	E	F	G	H
Elevation (inches)	0.00	1.42	4.81	6.51	9.28	12.12	9.63	4.55

Example 6.1 - Bottom Settlement

Tabulated below are relative elevations of the tank bottom taken at 8 points approximately 18.5 feet apart.

Settlement Data
(inches)

Location	A	B	C	D	E	F	G	H
Elevation	0.00	1.42	4.81	6.51	9.28	12.12	9.63	4.55
Rigid Plane Settlement	1.48	0.87	3.30	7.33	10.60	11.21	8.78	4.75
U_i	-1.48	0.55	1.51	-0.82	-1.32	0.91	0.85	-0.20
S_i	-1.66	0.54	1.65	-0.92	-1.37	1.15	0.50	0.12

A least squares fit of cosine curves of the elevation data gives a best fit plane inclined from 31 degrees to 211 degrees, with the lowest point at 31 degrees. The rigid plane settlements are calculated from the best fit cosine curve. U_i is the displacement from the rigid plane and is calculated by subtracting the rigid plane settlement from the elevation. S_i, the out-of-plane deflection, is obtained from the displacement from the rigid plane using the equation in Figure B-3 of API STD 653, or $S_i = [U_i - (U_{i-1} + U_{i+1})/2]$.

The maximum permissible out-of-plane deflection per API STD 653 is
$S \leq (L^2 \times Y \times 66)/(E \times H) = 0.47$ inches.

Where L = Arc length between measurements, in feet = 18.5 feet
Y = Yield strength, in psi = 30,000 psi
E = Young's Modulus, in psi = 30,000 psi
H = Tank height, in feet = 48 feet

The actual out-of-plane deflections exceed the permissible limit at 7 locations. Therefore, this tank should be releveled. However, per API STD 653, additional engineering analysis or assessment may be done to determine the acceptability of the existing settlement or the need for repairs/releveling.

6.2 Bottom Corrosion

Bottom corrosion that is not extensive enough to require bottom replacement must be evaluated and repaired per Sections 2 and 7 of API STD 653, or Sections 4 and 5 of API RP 12R1. The bottom repair or replacement criteria of RP 12R1 is straight forward. At the owner/operator's option, the bottom must be repaired or replaced if the thickness does not meet the criteria in Section 4.2.

Section 2 of API STD 653 requires that the bottom be repaired or replaced if the thickness does not satisfy Section 4, Table 4.1. The owner/operator may use a deterministic, probabilistic, or combination of the two methods to determine the MRT.

Example 6.2 illustrates the deterministic method of calculating the MRT with the use of tank bottom data obtained by the use of a floor scanner.

Example 6.2 - Bottom Corrosion

The bottom of a 100 foot diameter tank was measured using a floor scanning system. The tank had been in service for 10 years. The next internal inspection is scheduled in 10 years.

$\mathbf{T_o}$ = 0.25 inch
$\mathbf{GC_a}$ = 0.01 inch.
$\mathbf{StP_a}$ = 0.015 inch.
$\mathbf{StP_m}$ = 0.032 inch.
$\mathbf{UP_a}$ = 0.02 inch.
$\mathbf{UP_m}$ = 0.039 inch.
$\mathbf{StP_r}$ = 0.0032 inch per year.
$\mathbf{UP_r}$ = 0.0039 inch per year.
$\mathbf{GC_r}$ = 0.001 inch per year.
$\mathbf{O_r}$ = 10 years.

$$\mathbf{MRT_1 = T_o - GC_a - StP_a - UP_m - (StP_r + UP_r + GC_r)\, O_r}$$
$$\mathbf{MRT_2 = T_o - GC_a - StP_m - UP_a - (StP_r + UP_r + GC_r)\, O_r}$$

Substituting into the equations yields:

$$MRT_1 = 0.25 - 0.01 - 0.015 - 0.039 - (0.0032 + 0.0039 + 0.001)\ 10$$
$$MRT_1 = 0.105 \text{ inches}$$

$$MRT_2 = 0.25 - 0.01 - 0.032 - 0.02 - (0.0032 + 0.0039 + 0.001)\ 10$$
$$MRT_2 = 0.107 \text{ inch}$$

The tank meets the minimum thickness criteria of 0.1 inches.

7.0 SHELL EVALUATION

This section contains two examples of investigating the adequacy of a tank shell. Example 7.1 shows calculations for determining the minimum shell thickness ($t_{minimum}$) of an existing tank using the procedure given in API RP 12R1.

API STD 653 provides a procedure for evaluating a change in service, repair, or alteration to determine if the change increases the risk of a brittle failure to an API STD 650 tank. The procedure is charted in Figure 3-1 of API STD 653. Example 7.2 illustrates the procedure by applying it to an existing 100 foot diameter tank and shows the use of Figure 3-1 of API STD 653. Except under extreme arctic conditions, API 12 series tanks need not be evaluated for brittle fracture.

Example 7.1 - Minimum Shell or Ring Thickness

Determine the minimum thickness of an existing tank using the parameters in Appendix 6 of API RP 12R1. Quantities for the thickness calculation are:

D = 15 feet, 6 inches	Nominal tank diameter
H = 16 feet	Height of liquid level above bottom
G = 1.0	Design specific gravity of stored liquid
E = 0.7	Joint efficiency - no radiography
Y = 30,000 psi	Minimum yield strength of plate (A285 grade C steel)

See Appendix H 2.3.2 - 2.3.3

$$t_{minimum} = \frac{2.6(D)(H-1)(G)}{(0.80)(Y)(E)}$$

$$t_{minimum} = \frac{(2.6)(15.5)(16-1)(1.0)}{(0.80)(30,000)(0.7)}$$

$$t_{minimum} = 0.036 \text{ inch}$$

The minimum acceptable value is 0.062 inch. The calculated value is less than this, so 0.062 inch should be used as the minimum value.

Example 7.2 - Risk of Brittle Fracture

A 100 foot diameter by 48 foot high steel tank must be placed in service to store a petroleum product with a specific gravity of 0.85 and at ambient temperature. The tank does not meet API STD 650 7th edition material requirements. The owner has no records regarding a prior hydrostatic test on the tank, but the following data for minimum shell course thickness are available:

Course	Thickness (inches)
1	0.68
2	0.59
3	0.42
4	0.41
5	0.22
6	0.24

For the purpose of this example, assume that each shell course is 8 feet high and that the original joint efficiency is 1.0. Assume a location where the lowest one-day mean temperature is 15°F.

Evaluate the tank's suitability for resisting brittle fracture. Evaluation starts at Step 4 of API STD 653, Figure 3.1.

Step 4 Thickness of first 2 shell courses greater than 0.50 inch. Continue.

Step 5 Metal temperature is ambient. Therefore, the minimum-design metal temperature is 15°F + 15°F = 30°F which is less than 60°F. Continue.

Step 6 Is membrane stress less than 7 ksi (or 7,000 psi)? (See API STD 653, 2.3.3.1 for this formula and complete definition of terms)

$$S = \frac{2.6\ D\ (H - 1)\ G}{t_{min} E}$$

Where D is the nominal diameter, in feet
H is the height in feet
G is the highest specific gravity of the contents
t_{min} is minimum thickness for the shell course under consideration
E is the original joint efficiency of the tank.
[Note: use E = 0.7 if the original E is unknown]

Example 7.2 - Risk of Brittle Fracture (continued)

Shell course 1.

$$S = \frac{(2.6)\ (100)\ (48)\ (.85)}{0.68} = 15{,}600 \text{ psi} = 15.6 \text{ ksi}$$

Membrane stress of first course is greater than 7 ksi. Continue.

Step 7 Steel classification is unknown. Continue.

Step 8 No operating records available. Continue.

Step 9 Calculate fill height and consider restricting fill height to 7 ksi by rearranging the equation from Step 6 above and solving for H.

$$H = \frac{tES}{2.6\ (GD)} + 1$$

Check course 1:

The calculated height must be greater than the measured height from the bottom of the shell course to the maximum fill height or top of the tank. If it is not, the fill height must be reduced.

$$H = \frac{(20{,}000 \text{ psi})\ (0.68 \text{ inch} - 0.125 \text{ inch})}{(2.6)\ (100.0 \text{ feet})\ (0.85)} + 1.0$$

H = 51 feet > 48 feet Therefore O.K.

Check course 2:

$$H = \frac{(20{,}000 \text{ psi})\ (0.59 \text{ inch} - 0.125 \text{ inch})}{(2.6)\ (100.0 \text{ feet})\ (0.85)} + 1.0$$

H = 43 feet > 40 feet Therefore O.K.

Calculated shell course thicknesses are adequate for operating at the original design fill height of 48 feet.

Example 7.2 - Risk of Brittle Fracture (continued)

Calculate 7 ksi fill height for course 1. This is the fill height without a hydrostatic test, and the results show that the operating height is greatly reduced:

$$H_7 = \frac{(7{,}000 \text{ psi})\ (0.68 \text{ inch} - 0.125 \text{ inch})}{(2.6)\ (100.0 \text{ feet})\ (0.85)} + 1.0$$

$$H_7 = 18.6 \text{ feet}$$

A hydrostatic test to the full fill height of 48 feet is required to satisfy API STD 653 requirements for minimizing the risk of brittle fracture.

Appendix A

Summary of API Specification 12B

SUMMARY - API SPECIFICATION 12B*

SPECIFICATION FOR BOLTED TANKS FOR STORAGE OF PRODUCTION LIQUIDS

This specification covers materials, design, fabrication, and testing requirements for vertical, cylindrical, aboveground, bolted steel tanks subject to atmospheric internal pressure. It provides information on tanks used for storage of crude oil and other liquids commonly handled and stored by the oil production industry. The following summarizes the major sections of this API Specification.

Section 1 - Scope

This section includes information about the scope of the specification and compliance requirements.

Section 2 - Material

This section lists the acceptable API and ASTM specifications for plates, structural shapes, piping, flanges, couplings, and boltings. It also contains requirements for steel finish and coatings.

Section 3 - Design

API 12B tanks range in size from 100 to 10,000 barrels. Table 3.1 of this section lists the standard sizes and associated dimensions. Table 3.2 and Figures 3.2 through 3.7 give the number and configurations of bottom, shell and deck components. Thicknesses are given as minimum values. Minimum bottom plate thickness is 12-gauge or 10-gauge depending on the tank capacity. Minimum requirements for cleanouts, cover plates, piping, piping connections, and components also are provided.

Section 4 - Venting Requirements

This section requires that normal venting and emergency venting, except in specified circumstances, be provided. Pressure-vacuum values for normal venting are to be sized in accordance with API Standard 2000. It also discusses emergency venting capacity which must conform to the requirements listed in Table C.1.

Section 5 - Erection

This section provides requirements for erecting tank staves and cleanup.

* Thirteenth Edition, October 1, 1990. Reaffirmed 1994.

Section 6 - Marking

This section requires tanks manufactured per API RP 12B to be identified with a nameplate which conforms to the requirements listed in this section.

Section 7 - Inspection and Rejection

This section provides access for the purchaser/inspector during tank manufacture and outlines rejection criteria.

Appendix A - Specification for Tank Bolting

This appendix provides minimum physical properties and testing requirements for bolts and nuts used in API RP 12B tanks.

Appendix B - Recommended Practice for Normal Venting

This appendix contains Table B.1, Venting Capacity Requirements.

Appendix C - Recommended Relieving Capacities

This appendix contains two tables, Table C.1, Emergency Venting Requirements, and Table C.2, Calculated Venting Capacity of Thief Hatches.

Appendix D - Walkways, Stairways and Ladders

This appendix contains dimensions and load requirements for walkways, stairways and ladders.

Appendix B

Summary of API Specification 12D

SUMMARY - API SPECIFICATION 12D*

SPECIFICATION FOR FIELD WELDED TANKS FOR STORAGE OF PRODUCTION LIQUIDS

This specification covers materials, design, fabrication and testing requirements for vertical, cylindrical, aboveground, closed top, welded steel tanks operated at atmospheric pressure. It provides information on tanks used for storage of crude oil and other liquids commonly handled and stored by the oil production industry. The following summarizes the major sections of this API Specification.

Section 1 - Scope

This section includes information about the scope of the recommended practice and compliance requirements.

Section 2 - Material

This section lists the acceptable API and ASTM specifications for plates, structural shapes, piping, flanges, couplings and boltings. It also contains requirements for welding electrodes.

Section 3 - Design

API 12D tanks range in size from 500 to 10,000 barrels. Table 3.1 lists the standard sizes and associated dimensions, and Figure 3.1 provides illustrations. This section provides requirements for design of joints, decks, shell attachments, cleanouts, domes, piping, piping connections and other components.

Section 4 - Venting Requirements

This section requires that normal venting and emergency venting, except in specified circumstances, be provided. Pressure-vacuum values for normal venting are to be sized in accordance with API Standard 2000. It also discusses emergency venting capacity which must conform to the requirements listed in Table C.1.

Section 5 - Construction, Testing and Painting

This section contains construction, weld testing, external painting, internal coating, and cleanup requirements. It explains that bottoms of field erected tanks must be vacuum

* Ninth Edition, January 1982 with supplement issued May 1, 1985. Reaffirmed 1994.

tested and describes the procedure. It also describes methods for testing tanks by filling them with water for a period of not less than 12 hours or by air pressure testing at one and one-half times the design pressure.

Section 6 - Marking

This section provides that tanks manufactured per API RP 12D be identified with a nameplate which conforms to the requirements listed in this section.

Section 7 - Inspection and Rejection

This section provides access for the purchaser/inspector during tank manufacture and outlines rejection criteria.

Appendix A - Specification for Tank Bolting

This appendix provides minimum physical properties and testing requirements for bolts and nuts used in API RP 12D tanks.

Appendix B - Recommended Practice for Normal Venting

This appendix contains Table B.1, Venting Capacity Requirements.

Appendix C - Recommended Relieving Capacities

This appendix contains two tables, Table C.1, Emergency Venting Requirements, and Table C.2, Calculated Venting Capacity of Thief Hatches.

Appendix D - Walkways, Stairways and Ladders

This appendix contains dimensions and load requirements for walkways, stairways and ladders.

Appendix C

Summary of API Specification 12F

SUMMARY - API SPECIFICATION 12F*

SPECIFICATION FOR SHOP WELDED TANKS FOR STORAGE OF PRODUCTION LIQUIDS

This specification covers materials, design, fabrication and testing requirements for shop-fabricated vertical, cylindrical, aboveground, closed top, welded steel tanks operated at atmospheric pressure. It provides information on tanks used for storage of crude oil and other liquids commonly handled and stored by the oil production industry. The following summarizes the major sections of this API Specification.

Section 1 - Scope

This section includes information about the scope of the specification and compliance requirements.

Section 2 - Material

This section lists the acceptable API and ASTM specifications for plates, structural shapes, piping, flanges, couplings, and boltings. It also contains requirements for welding electrodes.

Section 3 - Design

API 12F tanks range in size from 90 to 750 barrels. Table 3.1 of this section lists the standard sizes and associated dimensions, and Figure 3.1 provides illustrations. Design requirements for appurtenances such as decks, shell attachments, cleanouts, drain baffles, piping, piping connections, and other components also are provided.

Section 4 - Venting Requirements

This section requires that normal venting and emergency venting, except in specified circumstances, be provided. Pressure-vacuum values for normal venting are to be sized in accordance with API Standard 2000. It also discusses emergency venting capacity which must conform to the requirements listed in Table C.1.

* Tenth edition, June 1, 1988. Reaffirmed 1994.

Section 5 - Fabrication, Testing and Painting

This section contains fabrication, welding, testing, external painting, and internal coating requirements. It requires that tanks be tested by applying air pressure and soap suds, linseed oil, or other suitable material to all welded joints to detect leaks.

Section 6 - Marking

This section requires that tanks manufactured per API SPEC 12F be identified with a nameplate which conforms to the requirements listed in this section.

Section 7 - Inspection and Rejection

This section provides access for the purchaser/inspector and outlines rejection criteria.

Appendix A - Specification for Tank Bolting

This appendix provides minimum physical properties and testing requirements for bolts and nuts used in API SPEC 12F tanks.

Appendix B - Recommended Practice for Normal Venting

This appendix contains Table B.1, Venting Capacity Requirements.

Appendix C - Recommended Relieving Capacities

This appendix contains two tables, Table C.1, Emergency Venting Requirements, and Table C.2, Calculated Venting Capacity of Thief Hatches.

Appendix D - Walkways, Stairways, and Ladders

This appendix contains dimensions and load carrying requirements of walkways, stairways, and ladders.

Appendix D

Summary of API Recommended Practice 12R1

SUMMARY - API RECOMMENDED PRACTICE 12R1*

RECOMMENDED PRACTICE FOR SETTING, MAINTENANCE, INSPECTION, OPERATION AND REPAIR OF TANKS IN PRODUCTION SERVICE

This Recommended Practice provides guidelines for: (1) setting and connecting lease tanks at new tank battery installations and in other production and treating service; (2) maintaining and operating lease tanks; and (3) inspecting and repairing tanks constructed in accordance with API 12 series (B, D, F and P) standards. This RP is intended primarily for application to tanks fabricated in accordance with API 12 series standards when employed in on-shore production services, but its basic principles are applicable to atmospheric tanks of other dimensions and specifications when they are employed in similar oil and gas production, treating, and processing services. It is not applicable to tanks in refineries, petrochemical plants, marketing facilities, or pipeline storage facilities.

Tanks fabricated to API STD 650 or its predecessor, API STD 12C, should be maintained in accordance with API STD 653.

This document recommends maintenance practices based on the estimated corrosion-rate life of various tank components. Corrosion-rate life of tank components will vary widely. For specific corrosion mitigation techniques, see other API publications or publications of the National Association of Corrosion Engineers (NACE). The following summarizes the major sections of this API Recommended Practice.

Section 1 - Scope

This section includes information about the scope of the recommended practice and compliance requirements.

Section 2 - Recommended Practice for Setting and Connecting Lease Tanks

This section includes the following subsections:

- *Setting of New or Relocated Tanks* -- Discusses location and spacing of tanks. It recommends that the foundation of the tank be designed and installed with certain features and gives information on supporting the tank so that it remains level and elevated; draining rainwater away from the tank; and ensuring that any fluids leaking through the bottom will drain to the perimeter of the tank. It also recommends that

* Fourth Edition, August 1, 1991

a plastic sheet or other impermeable barrier be placed over the sub-base if the soil is not sufficiently impermeable to prevent migration of fluids into soils below the tank. It also discusses retainer rings.

- *Proper Measurement and Sampling of Oil in Tanks Used for Measurement and Providing for Storage Efficiency* -- Provides information on location of the main hatch, pipeline connection, fill line, drain line and other features.

- *Delivery of Measured Quantities to Pipeline in Tanks Used for Measurement*

- *Tank Integrity* -- Describes practices for ensuring the integrity of tanks, including requirements for welded tanks, procedures for minimizing corrosive effects, and procedures for venting.

Section 3 - Recommended Practice for Safe Operation and Spill Prevention of Tanks

This section includes the following subsections:

- *Operating Safety* -- Describes safety requirements.

- *Spill Prevention* -- Provides recommendations for preventing spills and migration of spilled material.

Section 4 - Recommended Practice for Examination, Inspection and Maintenance of Tanks

This section discusses the need for an ongoing tank inspection program that assures tank integrity during normal service. Because the fitness-for-purpose and the structural integrity of a tank are important to assure its long-term, leak free condition, both internal and external observations are required. This section explains that observations are divided into examinations and inspections and explains the various classifications within those categories. Tables 1 and 2 of this section list the types of observations, frequency, and required personnel. This section includes the following subsections:

- *Maintenance* -- Explains the need for a preventive maintenance program to assure tank integrity and describes elements that should be included in such a program.

- *Routine Operational Examination* -- Explains that routine operational examinations should be made at least once a month for any in-service tank.

- *External Condition Examination* -- Explains that an unscheduled External Condition Examination should be made when a Routine Operational Examination results in finding an Operational Alert, malfunction, shell or deck leak, or potential bottom leak.

A scheduled External Condition Examination should be performed at least once a year for any in-service tank. The section explains what the examinations should include and the record keeping requirements.

- *Internal Condition Examination* -- Explains that an unscheduled Internal Condition Examination should be made when an Operational Alert or potential bottom leak report results from a Routine Operational Examination or from an External Condition Examination. A scheduled Internal Condition Examination is made when a tank is cleaned for normal operational requirements, when there is a change in tank location, when the service of the tank is changed more than five years after an Internal Inspection, when the tank is entered for any type of maintenance or modification, when ownership/operatorship changes, and adequate records are not available. The section also explains what the examinations should include and the record keeping requirements.

- *Internal/External Inspections* -- Explains that External and Internal Inspections may be scheduled based on the corrosion-rate life of the tank and should be performed by a Qualified Inspector. Corrosion rates may be either predicted from operational experience, or determined from measurements made in sampling tanks of the same class and similar service. An unscheduled inspection is required if a leak, severe wall pit, or severe roof deck corrosion is observed during an Internal or External Condition Examination. Scheduled External or Internal Inspections are based on the corrosion rate life of the tank and a calculation is given to determine this. The subsection also provides guidelines for External and Internal Inspection intervals.

- *Inspection Techniques* -- Describes external and internal inspections.

- *Shell Welds* -- Explains that the corrosion condition of shell welds should be visually evaluated to determine the need for further nondestructive inspection or repair.

- *Records* -- Describes recordkeeping requirements.

Section 5 - Recommended Practice for Alteration or Repair of Tanks

This section includes the following subsections:

- *Types of Repairs* -- Explains that alterations and repairs should be made when inspection results indicate that they are necessary. Describes types of repairs for storage tanks that do not involve welding or hot work.

- *Preparation of Tank for Repairs*

- *Minimum Thickness and Material Requirement of Replacement Shell Plate*

- *Weld Joints* -- Describes welding and inspection requirements, repair of welds, and acceptable criteria for existing shell plate to new shell plate welds.

- *Alteration of Tank Shells to Change Shell Height*

- *Repair of Shell Penetrations*

- *Hot Taps* -- Discusses preparation and considerations for hot taps.

- *Leak Detection on Bottom Replacement* -- Explains that when planning a tank bottom replacement, consideration should be given to removing the old bottom or providing a means of preventing galvanic corrosion and/or shielding of cathodic protection. When a tank bottom is replaced from inside the tank, a means for visual leak detection should be included in the refurbished unit.

- *Reconstruction of a Dismantled Tank* -- Provides requirements for reconstruction.

- *Required Hydrostatic Testing* -- Provides requirements for hydrostatic testing.

- *Nameplates*

Appendix 1 - Recommended Qualifications for Qualified Inspectors and Competent Persons

Appendix 2 - Example Calculations of Venting Requirements

Appendix 3 - Industry Observations and Experiences on Shell Corrosion and Brittle Fracture

Appendix 4 - Checklist for External Condition Examination

Appendix 5 - Checklist for Internal Condition Examination

Appendix 6 - Minimum Thickness for Tank Elements

This appendix provides minimum thickness criteria for predicting the corrosion rate life of API 12 B, D and F tank elements. It is intended to provide a safety factor of at least 5 years of remaining life.

Appendix 7 - Checklist for External Inspection

Appendix 8 - Checklist for Internal Inspection

Figure 1 - Example of Straight Line Tank Battery Installation and Piping Configurations

Figure 2 - Example of Small Volume Shop Welded Tank Foundation and Connection Configuration

Figures 3A and 3B - Example Tank Battery Installation Showing Dike/Firewall and Example Piping Configuration

Figure 4 - Corrosion Calculation Nomenclature

Appendix E

Summary of API Standard 650

SUMMARY - API STANDARD 650*

WELDED STEEL TANKS FOR OIL STORAGE

API STD 650 is applicable to flat bottom welded steel oil storage tanks with an internal pressure not exceeding 2.5 pounds per square inch. This specification is intended as a purchase specification for the petroleum industry. However, in practice it is used not just for oil storage, but as a basic specification in the chemical and petroleum industry for most, if not all, of the non-production related atmospheric storage tanks.

API STD 650 requirements are for flat bottom tanks containing liquids with little or no surface pressure. Like the ASME Code Section VIII Division 1, the equations and design philosophy are based on a minimum amount of analysis. The design rules are minimum requirements and may be supplemented.

The following summarizes the major sections of this API Standard.

Section 1 - Scope

The standard covers only tanks whose entire bottom is uniformly supported and tanks in nonrefrigerated service with a maximum operating temperature of 200°F unless the additional requirements of Appendix M (of this standard) are met. When Appendix M requirements are met and the material is Group I, II, III, or IIIA, the maximum temperature must not exceed 500°F.

Section 2 - Materials

This section discusses requirements for materials used in the construction of tanks. It includes the following subsections:

- *Plates* -- Describes the applicable standards from other organizations (ASTM, CSA, ISO). Discusses heat treatment of plates, impact testing, toughness requirements and procedures. Includes figures and tables on material groups.

- *Sheets* -- Lists standards to which sheets must conform.

- *Structural Shapes* -- Lists standards to which structural shapes must conform.

- *Piping and Forges* -- Lists standards to which pipe must conform.

* Ninth Edition, 1993

- *Flanges* -- Lists standards to which flanges must conform.
- *Bolting* -- Lists standards to which bolting must conform.
- *Welding Electrodes* -- Lists standards to which welding must conform.

Section 3 - Design

This section discusses requirements for materials used in the construction of tanks. It includes the following subsections:

- *Joints* -- Provides definitions of various joints, discusses weld size, restrictions on joints, and typical joints. The standard requires that all vertical shell joints be full penetration and complete fusion except that the top angles may have double welded lap joints.

- *Design Considerations* -- Describes the parameters the purchaser must specify such as design temperature, specific gravity, corrosion allowance and wind velocity. (API STD 650 tanks are not designed for external pressure, but experience suggests that they may safely be exposed to an external pressure of 1 inch of water.) The purchaser must also specify the nozzle loads so that the manufacturer may design the tank. Appendix P of this standard provides a procedure for determining the allowable external loads on tank shell openings.

- *Special Considerations* -- Discusses other design considerations such as the tank's foundation, corrosion allowance, service conditions, and weld hardness.

- *Bottom Plates* -- Provides requirements for bottom plates.

- *Annular Bottom Plates* -- Explains that when the bottom shell course is designed using allowable stresses of the high strength material group, an annular bottom plate is required.

- *Shell Design* -- Explains that the minimum shell thickness depends on the tank diameter, but provides the minimum thickness requirement of 3/16 inch. One should notice that two shell thicknesses must be calculated -- one based on the intended product and another on the hydrostatic test. The required thickness is the greater of the two. The subsection provides two methods for calculating shell thickness. The "1-Foot Method" calculates the thickness at a point one foot above the bottom of the shell course. The "Variable-Design-Point-Method," bases the thickness of the course on a more exact location for the point of maximum stress in the course. This method normally provides for thinner shell courses. The shell course allowable stress depends on the design method, product, or hydrostatic test thickness and location of the shell course.

- *Shell Openings* -- The requirements in this subsection are intended to restrict the use of appurtenances to those providing for attachment to the shell by welding. Reinforcement is required if the size of the opening is greater than a 2 inch NPS standard weight coupling. The subsection also discusses requirements for spacing of welds around connections, thermal stress relief, shell manholes (including figures and tables regarding thickness and dimensions), shell nozzles and flanges (including figures and tables), flush-type cleanout fittings, and flush-type shell connections (including figures and tables).

- *Shell Attachments and Tank Appurtenances* -- Discusses shell attachments, bottom connections, cover plates, roof manholes, roof nozzles, water-drawoff sumps, scaffold-cable support, threaded connections, and platforms, walkways, and stairways, with the appropriate figures and tables.

- *Top and Intermediate Wind Girder Design* -- Requires that open top tanks have a stiffening ring at or near the top course. (Most if not all API STD 650 tanks have a top stiffening ring. This section requires the ring for floating-roof tanks; this is the best way to support the roof on closed tanks. Note that the top and intermediate wind girders will be based on a wind velocity of 100 miles per hour unless the manufacturer is told otherwise.) Discusses other aspects of girder design using figures and tables.

- *Roof Design* -- Describes requirements for various types of roofs and the requirement for a frangible roof-to-shell joint. Explains that if the tank is designed with frangible roof joints then emergency venting devices are not required. A tank without frangible roof joints must install emergency venting in accordance with API Standard 2000. (Note that API STD 650 does not have any requirements regarding bearing loads on the floor plates. The purchaser must specify them if they are desired.)

- *Wind Load on Tanks (Overturning Stability)* -- Describes calculations.

Section 4 - Fabrication

This section discusses the requirements for fabrication of tanks including workmanship, finish of plate edges, shaping of shell plates, marking, shipping, and shop inspection.

Section 5 - Erection

This section contains fit-up tolerances, inspection, testing, and repair requirements. It discusses welding of bottoms, shells, and roofs and how each of the welds should be inspected. (API STD 650 states that the manufacturer must pay for all required radiographs as well as those requested by the purchaser if defects are disclosed.) On completion of the tank and before external piping has been connected, the standard requires testing of the shell and specifies procedures for this including hydrotesting, air testing, vacuum testing, or painting with a highly penetrating oil. Relief from the hydrostatic test is allowed only if water is not available.

Foundation tolerances are given for concrete ringwalls and compacted soil. As currently written the section does not provide for elevated tanks or tanks on concrete foundations, which do not provide uniform support.

Section 6 - Methods of Inspecting Joints

This section discusses the radiographic inspection that is required for all butt welds. The number and location of spot radiographs are discussed in this section. The technique and acceptability standard is per ASME's Boiler and Pressure Vessel Code. The section also discusses use of Magnetic Particle, Ultrasonic, and Liquid Penetrant, and Visual examinations.

Section 7 - Welding Procedure and Welder Qualifications

This section describes requirements for qualification of welding procedures, qualification of welders, and identification of welded joints.

Section 8 - Markings

This section contains the requirement for at least one nameplate on each completed tank. The erection manufacturer has primary responsibility when there is more than one manufacturer involved. The section also provides an example of a certification letter.

Appendix A - Optional Design Basis For Small Tanks

This appendix includes requirements for relatively small tanks with relatively simple designs (with figures and tables). The allowable stress is 21,000 psi regardless of the material. Thickness of all stress led components is limited to 0.5 inch including corrosion allowance.

Appendix B - Recommendations for Construction of Foundations for Vertical Cylindrical Oil Storage Tanks

This appendix contains recommendations for the design and construction of tank foundations. The tank manufacturer is normally not responsible for the tank foundation. However, the construction tolerances of the completed tank (i.e., peaking and banding requirements) depend upon the foundation.

Appendix C - External Floating Roofs

This appendix contains minimum requirements for pan-type, pontoon-type, and double-deck-type floating roofs.

Appendix D - Technical Inquiries

This appendix describes procedures for requesting interpretations of standards.

Appendix E - Seismic Design of Storage Tanks

This is an in-depth appendix on how to design tanks for seismic loads.

Appendix F - Design of Tanks for Small Internal Pressures

This appendix discusses the design of tanks with an internal pressure up to and including 2.5 pounds per square inch.

Appendix G - Structurally Supported Aluminum Dome Roofs

Appendix H - Internal Floating Roofs

This appendix provides minimum requirements that apply to the floating roof of a tank with a fixed roof at the top of its shell and apply to the tank appurtenances.

Appendix I - Undertank Leak Detection and Subgrade Protection

Appendix J - Shop-Assembled Storage Tanks

This appendix provides for the shop fabrication of small tanks (20 feet in diameter or less) per API STD 650. (These tanks are usually of a higher quality than non-API STD 650 shop fabricated tanks.)

Appendix K - Example of Application of the Variable-Design-Point Procedure to Determine Shell-Plate Thicknesses

This appendix provides an example with calculations and tables.

Appendix L - API STD 650 Storage Tank Data Sheets

This appendix provides data sheets to be used by the purchaser in ordering a storage tank and by the manufacturer upon completion of construction.

Appendix M - Elevated Temperature Requirements

API STD 650 tanks may be designed to operate at temperatures up to and including 500° F. This appendix provides the additional requirements if tanks are to be operated at temperatures exceeding 200° F.

Appendix N - Use of Materials that Are On Hand but Are Not Identified as Complying with Any Listed Specification

This appendix presents conditions for the use of materials that are on hand but are not completely identified by this standard as complying with any listed specification.

Appendix O - Recommendations for Under-Bottom Connections

This appendix contains basic recommendations to be considered in the design and construction of under-bottom connections for storage tanks.

Appendix P - Allowable External Loads on Tank Shell Openings

This appendix contains recommended minimum requirements for the design of openings that conform to Table 3-8 and are subjected to external piping loads.

Appendix F

Summary of API Recommended Practice 651

SUMMARY - API RECOMMENDED PRACTICE 651*

CATHODIC PROTECTION OF ABOVEGROUND PETROLEUM STORAGE TANKS

This Recommended Practice describes the corrosion problems characteristic in aboveground steel storage tanks and associated piping systems used for storing hydrocarbons. It provides a general description of the two methods currently used to provide cathodic protection against corrosion. The following summarizes the major sections of this Recommended Practice.

Section 1 - General

Section 1 provides definitions and a list of references.

Section 2 - Corrosion of Aboveground Steel Storage Tanks

This section provides a primer on the definition and causes of corrosion. It explains that corrosion is an electrochemical process in which the metal of a steel structure deteriorates by reacting with the environment. The corrosion process occurs when areas with different electrical potentials exist on the metal surface. An electrochemical corrosion cell is formed which allows the metal to corrode. The two most common types of corrosion observed in tank bottoms are "general" and "pitting" corrosion.

Stray currents (also known as interference currents) may enter an unprotected tank bottom and travel through the low resistance path of the metal. The stray currents need to be detected and controlled to prevent corrosion. Using dissimilar metals during the fabrication and installation of tank and pipe can also cause bimetallic corrosion.

Section 3 - Determination of Need for Cathodic Protection

This section discusses parameters that must be considered when determining whether an AST requires cathodic protection. It explains that the decision to use cathodic protection for the tank should be based on data from corrosion surveys, operating records, prior test results with similar tank systems in similar environments, national, state and local code requirements, and the recommendations made within this RP.

This section explains that new aboveground storage tanks should be protected from corrosion by designing and maintaining the cathodic protection system during the service life of the tank unless detailed studies indicate that this corrosion protection is

* First Edition, April 1991

unnecessary. For existing aboveground tanks the possible need for cathodic protection should be made after completion of studies, within a suitable time frame in accordance with API STD 653, "Tank Inspection and Repair."

This section explains that cushion material under a tank has a significant effect on external corrosion of the tank bottom and can influence the effectiveness and applicability of external cathodic protection. External cathodic protection is an effective means of corrosion control if electric current can flow between the anode and cathode (tank bottom). This section also describes features of various types of cushioning and discusses factors which can limit the effectiveness of cathodic protection including foundations and soil conditions, an impervious lining between the tank bottom and anodes, and old storage tank bottoms left in place when a new bottom is installed.

Section 4 - Methods of Cathodic Protection for Corrosion Control

This section describes cathodic protection as a recognized method of corrosion control that, when properly applied, can reduce or eliminate corrosion of aboveground steel storage tank bottoms. This section describes the two methods of cathodic protection -- sacrificial anode (generally applied only to small diameter tanks) and impressed current (generally used to protect large diameter tanks) -- and explains the advantages and disadvantages of each.

Section 5 - Design of Cathodic Protection Systems

This section describes the objectives of cathodic protection designs for tank bottoms. It provides a list of procedures for designing cathodic protection systems and discusses the influence of replacement bottoms, linings, and secondary containment on the design, making clear that anything that acts as a barrier to the flow of current will prevent the successful application of cathodic protection. Use of an impervious membrane for secondary containment and replacement bottoms can have such an effect if not considered properly. This section provides tips for alleviating potential problems. It also includes a short subsection on internal cathodic protection.

Section 6 - Criteria for Cathodic Protection

This section lists criteria for cathodic protection that indicates when adequate cathodic protection is achieved and includes measurement techniques.

Section 7 - Installation of Cathodic Protection Systems

This section provides procedures for installing cathodic protection systems. It discusses both sacrificial anode and impressed current systems with appropriate figures showing different types of installation situations. It also discusses corrosion control test stations, connections and bonds.

Section 8 - Interference Currents

The purpose of this section is to assist in the identification of sources of interference currents and recommend practices for the detection and control of these currents. The section explains that interference current is an undesirablė discharge of current from a structure caused by electrical current from a foreign source. Interference is normally from a DC source such as an electric railway, rapid transit system, underground mining, electrical systems, welding machines, and in some cases, from rectifiers energizing nearby cathodic protection systems. AC currents also cause interference problems. The section describes three main approaches to resolving interference current problems.

Section 9 - Operation and Maintenance of Cathodic Protection Systems

This section recommends procedures and practices for energizing and maintaining continuous, effective, and efficient operation of cathodic protection systems. It explains the necessity for electrical measurements and inspections to ensure the system works properly and notes that conditions that affect protection are subject to change with time. For this reason, periodic measurements and inspection are necessary to detect changes in the cathodic protection system and make necessary changes to ensure continued protection.

This section recommends annual cathodic protection surveys to ensure the effectiveness of cathodic protection and describes the types of measurements that should be included as well as other inspections/examinations that should be made. It also describes the corrosion control records which should be kept.

Appendix G

Summary of API Recommended Practice 652

SUMMARY - API RECOMMENDED PRACTICE 652*

LINING OF ABOVEGROUND PETROLEUM STORAGE TANK BOTTOMS

The purpose of this Recommended Practice is to present procedures and practices for achieving effective corrosion control in aboveground storage tanks by application of internal tank bottom linings. It contains provisions for application of tank bottom linings to existing and new storage tanks. This RP is only a guide and does not include detailed lining specifications. While the included practices may be applicable to tanks in other services, the intent is to provide guidance for lining tanks in hydrocarbon service. The following summarizes the major sections of this Recommended Practice.

Section 1 - General

This section provides definitions and references.

Section 2 - Corrosion Mechanisms

This section discusses common mechanisms of internal storage tank bottom corrosion in the following subsections:

- *Chemical Corrosion* -- Explains that this corrosion results from the improper use of chemicals which attack the metal and may occur in environmental and product cleanup tanks as well as chemical storage tanks. Provides examples.

- *Concentration Cell Corrosion* -- Explains that this corrosion occurs when a surface deposit, mill scale, or crevice creates a localized area of lower oxygen concentration. The difference in oxygen concentration between the area and the bulk electrolyte creates a galvanic cell, with the contact area of the surface deposit being anodic to the surrounding tank plate. Concentration cell corrosion will cause pitting with rates as high as 80 mils per year in bare steel tank bottoms.

- *Galvanic Cell Corrosion* -- Explains that mill scale, which is cathodic to base steel in the presence of a corrodent and an electrolyte, can form a bi-metallic corrosion couple at breaks in the mill scale. The resulting couple can cause accelerated pitting. Welding, because of the differences in microstructure, can also produce galvanic corrosion couples.

- *Corrosion Caused By Sulfate Reducing Bacteria* -- Explains that sulfate reducing bacteria (SRB) are widespread in the petroleum industry. SRB corrosion is not well

* First Edition, January 1991

understood and generally has negligible effect on the corrosion of bare steel storage tank bottoms. However, under certain circumstances, SRB may promote concentration cell corrosion or galvanic corrosion.

- *Erosion/Corrosion* -- Explains that erosion/corrosion may occur in waste water treating or mixing tanks where soil or small abrasive aggregates are present. It can occur to a lesser extent at tank mixers in crude oil tanks. Erosion/corrosion causes high localized metal loss in a well-defined pattern.

Section 3 - Determination of the Need for Tank Bottom Lining

This section describes the considerations on which the need for an internal tank bottom lining is generally based. It includes the following subsections:

- *Corrosion Prevention* -- Explains how proper selection and application of tank bottom linings can prevent internal corrosion of the steel tank bottom. Unless means of corrosion prevention on the soil side are used, however, perforation of the tank bottom may still occur. Thick film linings may help to reduce the potential for leakage if perforation of the steel bottom occurs.

- *Tank Design* -- Explains how existing tanks may have design and fabrication features, for example internal steam coils, that would make the application of a lining impractical or that would seriously jeopardize the integrity of a lining.

- *Tank History* -- Recommends that the corrosion history of a particular tank and tanks in similar service be considered when determining the need for an internal lining. This subsection discusses some of the more important considerations.

- *Environmental Considerations* -- Specifies items that should be considered in prioritizing the application of linings to the bottom of aboveground storage tanks for which the need of a lining has been determined.

- *Flexibility for Service Change* -- Explains that tank linings do not offer universal resistance. Changes in service may affect the performance of tank bottom linings. Such factors should be considered during the selection and design of a lining system.

- *Upset Conditions* -- Explains how a relatively short-term exposure to an unusually aggressive environment can cause irreversible damage to a lining. A lining must be selected to resist potential upset conditions in addition to the usual service environment.

Section 4 - Tank Bottom Lining Selection

Tank bottom linings can generally be divided into two classes: thin film (20 mils or less), and thick film (greater than 20 mils). Generally, thin film linings are applicable to new tanks and to existing tanks that have experienced minimal corrosion. Subsections describe the advantages and disadvantages of the different linings and other considerations:

- *Thin Film Tank Bottom Linings* -- Table 1 of this subsection lists generic types of thin film coatings and their suitability for various stored hydrocarbon and petrochemical products. All linings employed to protect tank bottoms must also be resistant to water. According to this subsection, the principal advantage of thin film linings is lower cost and ease of application.

- *Thick Film Tank Bottom Linings* -- Explains that thick film coatings may be used as tank bottom linings for both new and old tanks. The generic types of thick lining systems in common use are listed in Table 2 of this subsection. These systems are commonly reinforced with various types of glass or organic fibers. This subsection also explains why thick film linings are used in preference to thin film linings on older tanks where internal corrosion has occurred. The importance of surface preparation, and disadvantages of these linings are also discussed.

- *Design of Storage Tank Bottom Linings* -- Describes other aspects of design of tank bottom linings, including coverage of lining, number of coats that needs to be applied, and other information.

- *Exceptional Circumstances Affecting Lining Selection* -- Explains how tank operating temperature and product purity may affect selection of linings.

Section 5 - Surface Preparation

This section describes the importance of surface preparation and the subsections discuss each aspect:

- *Precleaning* -- Discusses the necessity for removing all oil, tar, grease, salt, and other contaminants before blasting.

- *Bottom Repair and Weld Preparation*

- *Abrasive Blasting* -- Discusses the temperature and humidity parameters for abrasive blasting and explains the necessity of restoring degraded surfaces before applying the lining.

- *Surface Profile or Anchor Pattern*

- *Types and Quality of Abrasives*

Section 6 - Lining Application

This section describes guidelines for lining application, temperature and humidity control, lining thickness considerations, and lining curing.

Section 7 - Inspection

This section describes lining inspections and includes references for the inspection procedure documents that should be followed. The lining should be inspected during application and upon completion.

Section 8 - Repair of Tank Bottom Linings

This section explains that a properly applied lining will provide a service life of 10-20 years. It provides guidelines for repair in these subsections:

- *Determine Cause of Failure*

- *Types of Repair* -- Discusses the three basic tank lining repair procedures (spot repair, topcoating, and relining) and when they are used.

- *Coating Manufacturer's Recommendations*

Section 9 - Safety

This section provides general safety information and a list of practices and guidelines which should be consulted when applying a lining.

Appendix H

Summary of API Standard 653

SUMMARY - API STANDARD 653*

TANK INSPECTION, REPAIR, ALTERATION, AND RECONSTRUCTION

This standard provides minimum requirements for the inspection, repair, alteration and reconstruction of carbon and low alloy steel tanks built to the specifications of API STD 650 and its predecessor. The basic principles of this standard are applicable to any welded or riveted, non-refrigerated atmospheric pressure steel tank.

This standard is to be used by experienced engineers and inspectors. The following hierarchy must be followed when applying this standard:

- API Standard 653
- Original standard of construction
- Current edition of the original standard of construction
- API Standard 650

The following summarizes the major sections of this Standard.

Section 1 - Introduction

This section provides definitions and references.

Section 2 - Suitability for Service

This standard requires that an evaluation of a tank's suitability for continued use be made when the results of a tank inspection show that a change has occurred from the original physical condition of that tank. This section provides a format for evaluating the suitability of an existing tank for continued service or for a change in service and provides a guide for making decisions regarding repairs, alterations, dismantling, relocating or reconstructing an existing tank. This section includes the following subsections:

- *Tank Roof Evaluation* -- Contains requirements for thickness of roof plates. Discusses inspections of fixed roofs and floating roofs. Also discusses roof requirements when the tank service is changed. Includes requirements to use the following references:

* First Edition, January 1991

Condition or Component	**Standard**
Floating Roof	API Standard 650
Internal Pressure Change	Applicable Standard
External Pressure Change	API Standard 620
Temperature Increase to > 200°F	API Standard 650
Temperature Decrease	Applicable Standard or API Standard 650

- *Tank Shell Evaluation* -- Requires that conditions which might adversely affect the structural integrity of the tank be evaluated. Requires that the evaluation of the shell be conducted by personnel experienced in tank design and be based on existing thickness and materials, and consider all anticipated loading conditions. Discusses actual thickness determination; minimum thickness calculation for a welded tank shell and a riveted tank shell; and evaluation of distortions, flaws, windgirders, shell stiffeners, shell welds and shell penetrations.
- *Tank Bottom Evaluation* -- Requires periodic assessment of tank bottom integrity and examination of each aspect of corrosion phenomena, and other potential leak or failure mechanisms. Provides a list of historical causes of bottom leakage or failure and gives references for cathodic protection, internal lining, and procedures for calculating the minimum remaining thickness of the bottom and of the annular plate ring.
- *Tank Foundation Evaluation* -- Describes the causes of foundation deterioration and requires periodic inspection of tank foundations.

Section 3 - Brittle Fracture Considerations

This section provides a decision tree (Figure 3-1) that may be used to assess the risk of failure due to brittle fracture. The figure applies to riveted and welded tanks. It is based on data which shows that once a tank has demonstrated the ability to withstand the combined effects of maximum liquid level and lowest operating temperature without failure, the risk of a failure due to brittle fracture with continued service is minimal. The section also requires that any change in service or repair/alteration be evaluated to determine if it increases the risk of a brittle failure.

Section 4 - Inspection

This section includes various requirements for inspections including that tanks be inspected by a qualified inspector as defined in subsection 4.10. It includes the following subsections:

- *Inspection Frequency Considerations* -- Lists the factors that must be considered when determining inspection intervals. It also specifies other factors to take into account, such as its history.

- *External Inspection* -- Provides requirements for inspecting tanks and discusses what is included in the inspections. Discusses external inspections, scheduled inspections, in-service ultrasonic thickness measurement of the shell, internal inspections and alternatives to internal inspection to determine bottom thickness. It also describes the requirements for records, reports, and inspector qualifications.

Section 5 - Materials

This section provides general requirements for the selection of materials for the repair, alteration, and reconstruction of existing tanks. It requires that all new materials used for repair, alteration or reconstruction conform to the current applicable tank standards. It also provides requirements for original materials for reconstructed tanks.

Section 6 - Design Consideration for Reconstructed Tanks

This section provides requirements for new weld joints, existing weld joints, shell design, shell penetrations, windgirders and shell stability, roofs, and seismic design.

Section 7 - Tank Repair and Alteration

This section specifies that the basis for repairs and alterations shall be API STD 650 or its equivalent. It contains the following subsections:

- *Removal and Replacement of Shell Plate Material* -- Provides requirements for minimum thickness and dimensions of the replacement shell plate material. Also provides requirements for weld joint design.

- *Repair of Defects in Shell Plate Material* -- Explains that the need for repairing flaws such as cracks, gouges or tears discovered during an inspection is determined on an individual basis. Provides requirements for certain repairs.

- *Alteration of Tank Shells to Change Shell Height*

- *Repair of Defective Welds*

- *Repair of Shell Penetrations*

- *Addition or Replacement of Shell Penetrations*

- *Alteration of Existing Shell Penetrations*

- *Repair of Tank Bottoms* -- Provides requirements for repairing a portion of the tank bottom and replacement of the entire bottom. Requires that when planning a bottom replacement, consideration be given to removing the old bottom or providing other means of preventing galvanic corrosion. (Consideration should also be given to installing a leak detection system.)

- *Repair of Fixed Roofs* -- Provides the minimum thickness of new roof plates for supported cone roofs and the nominal thickness of new roof plates for self-supported roofs.

- *Floating Roofs* -- Explains that an external floating roof may be repaired with any method that restores the roof to a condition that enables it to perform its original function. Provides other requirements.

- *Repair or Replacement of Floating Roof Perimeter Seals* -- Provides requirements for repairing primary seals, secondary seals, seal-to-shell gap, mechanical damage, and deterioration of seal material. Also discusses installation of primary and secondary seals.

- *Hot Taps* -- These requirements cover radial hot tap connections on tanks with shell material that does not require postweld heat treatment. It specifies connection size and shell thickness limitations and other requirements.

Section 8 - Dismantling and Reconstruction

This section provides procedures for dismantling and reconstructing existing welded tanks that are to be relocated from their original site. It includes the following subsections:

- *Dismantling Methods* -- Provides requirements for reusable bottom plates, shell plates, roofs, and piece marking.

- *Reconstruction* -- Provides reconstruction requirements for welding, bottoms, and roofs.

- *Dimensional Tolerances* -- Provides requirements for plumbness, roundness, peaking, banding, and foundations.

Section 9 - Welding

This section provides requirements for welding and welders.

Section 10 - Examination and Testing

This section provides requirements for examination and testing of tanks in the following subsections:

- *Nondestructive Examination* -- Specifies when different types of examinations (e.g., ultrasonic, visual, magnetic particle, liquid penetrant, etc.) should be conducted for: shell penetrations, repaired weld flaws, temporary and permanent attachments to shell plates, shell plate to shell plate welds, shell-to-bottom welds, and bottom joints.

- *Radiographs* -- Provides requirements for the number and locations of radiographs.

- *Hydrostatic Testing* -- Explains that hydrostatic testing is required on a reconstructed tank and any tank that has undergone major repairs or major alterations as explained in this section. Also explains when hydrostatic testing is not required.

- *Leak Tests* -- Requires an air leak test for new or altered reinforcing plate of shell penetrations.

- *Measured Settlement During Hydrostatic Testing* -- Provides requirements for initial survey and survey during hydrostatic testing.

Section 11 - Marking and Recordkeeping

This section provides requirements for nameplates, recordkeeping, and certification.

Appendix A - Background on Past Editions of API Welded Storage Tank Standards

Appendix B - Evaluation of Tank Bottom Settlement

Appendix C - Checklists for Tank Inspection

Appendix D - [Reserved for Future Use]

Appendix E - Technical Inquiries

Order No. 849-32700

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