



**API 653: Tank Inspection Code:  
Inspection, repair, alteration, and  
reconstruction of steel aboveground storage  
tanks used in the petrochemical industry  
(Training only)**

**January 8-12, 2005  
Abu Dhabi, U.A.E.**

**Course Instructor(s)  
*Mr. Ron VanArsdale***



## To The Participant

The Course notes are intended as an aid in following lectures and for review in conjunction with your own notes; however they are not intended to be a complete textbook. If you spot any inaccuracy, kindly report it by completing this form and dispatching it to the following address, so that we can take the necessary action to rectify the matter.

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## **Disclaimer**

The information contained in these course notes has been compiled from various sources and is believed to be reliable and to represent the best current knowledge and opinion relative to the subject.

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## **COURSE OVERVIEW IE400**

### **API 653: Tank Inspection Code: Inspection, repair, alteration, and reconstruction of steel aboveground storage tanks used in the petrochemical industry (Training only)**

#### **Course Title**

API 653: Tank Inspection Code: Inspection, repair, alteration, and reconstruction of steel aboveground storage tanks used in the petrochemical industry (Training only)

#### **Course Date / Venue**

January 08 -12, 2005 / Al Hosn suite, 2<sup>nd</sup> Floor, Le Royal Meridien, Abu Dhabi, UAE.

#### **Course Reference**

IE400

#### **Course Duration**

Five days (40 hours as per API regulations)

#### **Course Objectives**

In order to meet the needs of today's fast changing inspection industry, Harvard Technology has developed the "Tank Inspection Course with API 653 Exam Prep.". The course textbook includes notes and summaries on the tank inspection standards referenced in the API 653 Body of Knowledge.

This comprehensive 40 hour course consists of five 8-hour teaching days. It is designed to accomplish a two-fold training agenda:

- (1) To train those individuals who are interested in obtaining the API 653 Tank Inspection Certification.
- (2) Train those who require a working knowledge of the intricacies encountered in the working environment.

Additionally, quizzes are given at the end of each section; homework is handed out at the end of each class day, which consists of 30 questions per day and is reviewed at the beginning of the following day, and a "practice" exam is administered at the end of the course. **Harvard Technology is proud of the 90%+ pass rate attained by its students who have sat for the API 653 certification exam.**

#### **Who Should Attend**

The course is intended for Inspection Engineers who are seeking API-653 certification. Other engineers, managers or technical staffs who are dealing with Steel Aboveground Storage Tanks used in the Petrochemical Industry will also benefit.



### **Course Instructor**

**Mr. Ron VanArsdale, PE, USA**, is the founder of Inspection Training And Consulting Company (ITAC). His duties include conducting training courses for **Harvard Technology and ITAC**, creating new courses for inspection and other related activities, creating course material, as well as developing custom training programs, customized written practices and providing trouble-shooting consulting services. In the past, Mr. VanArsdale was employed by **SGS Industrial Services as the Training Director** and the **American Welding Society (AWS)** as the **Curricula and Course Development Manager**. In this position he developed various training courses dealing with the **AWS Certified Welding Inspector program**. He **planned, organized, and developed all phases of educational activities for AWS**.

In addition to these functions, he is a **member of the API 653 Questions Committee** which **devised the API 653 Tank Inspector Certification Examination**; as well as a member of the **API 570 Questions Committee** which is charged with **developing the API 570 Piping Inspector Certification Examination**.

Ron attended **San Jacinto College** and **Texas A&M University**, and has a **Lifetime Teaching Certificate from the State of Texas**.

He is an **AWS Certified Welding Inspector (CWI)**, **ITAC Level III**, an **API Certified Aboveground Storage Tank Inspector**, and **API Certified Piping Inspector**, an **AWS Certified Welding Educator (CWE)** and is an internationally recognized Presenter/Instructor. Additionally, he received the **AWS Distinguished Member Award in March, 1989**, the **AWS CWI of the Year District Award in January, 1993**, as well as the **AWS District 18 Meritorious Award in September, 1993**.

He has **thirty-three years experience** in the erection, maintenance and inspection of buildings, petrochemical facilities, vessels, above-ground storage tanks, piping systems, in addition to teaching welding/inspection education courses.

Mr. VanArsdale is **professionally affiliated with the American Welding Society, American Society for Nondestructive Testing, American Petroleum Institute, Vocational Industrial Clubs of America, Harvard Technology, American Inspection Society, the National Job Core** and has been appointed a **Kentucky Colonel by the Governor of Kentucky in recognition of his lifetime contribution to his fellow man**.

### **Course Certificate**

Harvard Technology certificate will be issued to all attendees completing minimum of 75% of the total tuition hours of the course.

### **Course Fee**

US \$2,750 per Delegate. This rate includes Participant's Pack (Folder, Manual, Hand-outs, etc.), buffet lunch, coffee/tea on arrival, morning & afternoon of each day.



### **Accommodation**

Accommodation is not included in course fees. However, any accommodation required can be arranged by Harvard Technology at the time of booking.

### **Required Codes And Standards:**

Listed below are the effective editions of the publications required for the current Tank Inspector Certification Examination. Each student must purchase and have these documents available for use during the class. The course fee doesn't include the cost of those codes & standards.

- ◆ **API Recommended Practice 575**, Inspection of Atmospheric and Low-Pressure Storage Tanks, First Edition, November, 1995. Global Engineering Product Code API CERT 575
- ◆ **API Standard 650**, Welded Steel Tanks for Oil Storage, Tenth Edition, November 1998, including Addendum 1 (March 2000) and Addendum 2 (November 2001), Addendum 3 (September 2003). Global Engineering Product Code API CERT 650
- ◆ **API Recommended Practice 651**, Cathodic Protection of Aboveground Petroleum Storage Tanks, Second Edition (December 1997). Global Engineering Product Code API CERT 651
- ◆ **API Recommended Practice 652**, Lining of Aboveground Petroleum Storage Tank Bottoms, Second Edition (December 1997). Global Engineering Product Code API CERT 652
- ◆ **API Standard 653**, Tank Inspection, Repair, Alteration, and Reconstruction, Third Edition, December 2001 and Addendum 1 (September 2003). Global Engineering Product Code API CERT 653
- ◆ **American Society of Mechanical Engineers (ASME), Boiler and Pressure Vessel Code, 2001 Edition with 2002 and 2003 Addenda.**
  - i. **ASME Section V**, Nondestructive Examination, Articles 1, 2, 6, 7 and 23 (Section SE-797 only).
  - ii. **ASME Section IX**, Welding and Brazing Qualifications

*Global Engineering Product Code for the ASME package is API CERT ASME 653. Package includes only the above excerpts necessary for the exam. Future addenda will not be provided.*

*API and ASME publications may be ordered through **Global Engineering Documents** at +1-303-792-2181 or +1-800-854-7179. Product codes are listed above. **API members are eligible for a 50% discount on all API documents**, other exam candidates are eligible for a 20% discount on all API documents. No discounts will be made for ASME documents. When calling to order please identify yourself as an exam candidate. For complete sets of ASME documents including future addenda please contact ASME's publications department at +1-800-843-2763. In Canada, ASME publications are available through **Power Engineering Books, Ltd.** at +1-800-667-3155 or +1-780-458-3155.*

**Note: API and ASME publications are copyrighted material. Photocopies of publications are not permitted at the exam. CD-ROM versions of the API documents are issued quarterly by Information Handling Services. Be sure to check your CD-ROM against the editions noted on this sheet.**



## Course Program

### **Day 1 : Saturday 08<sup>th</sup> January 2005**

0730 - 0800	Registration & Coffee
0800 - 0815	Welcome
0815 - 0900	<b>Introduction</b>
0900 - 0930	<b>Students Take Initial Math Quiz</b>
0930 - 1000	<b>Review Math Quiz Answers</b>
1000 - 1015	Break
1015 - 1045	<b>Overview of Course Outline</b>
1045 - 1230	<b>Review of API 653 Body of Knowledge</b>
1230 - 1330	Lunch
1330 - 1445	<b>API 653 - Section 1 - Introduction:</b> General, Compliance With This Standard, Jurisdiction, Safe Working Practices, Definitions, Referenced Publications <b>API 653 - Section 2 - References</b> <b>API 653 - Section 3 - Definitions</b>
1445 - 1500	Break
1500 - 1620	<b>API 653 - Section 4 - Suitability For Service:</b> General, Tank Roof Evaluation, Tank Shell Evaluation, Tank Bottom Evaluation, Tank Foundation Evaluation
1620 - 1720	<b>API 653 - Section 5 - Brittle Fracture Considerations:</b> General, Basic Considerations, Assessment Procedure
1720 - 1730	Distribute Homework
1730	End of Day One

### **Day 2 : Sunday 09<sup>th</sup> January 2005**

0730 - 0830	Review Homework Answers
0830 - 1000	<b>API 653 - Section 6 - Inspection</b> General, Inspection Frequency Considerations, Inspections from the Outside of the Tank, Internal Inspection, Alternative to Internal Inspection to Determine Bottom Thickness, Preparatory Work for Internal Inspection, Inspection Checklists, Records, Reports, Non-Destructive Testing
1000 - 1015	Break
1015 - 1130	<b>API 653 - Section 7 - Materials</b> General, New Materials, Original Materials for Reconstructed Tanks, Welding Consumables
1015 - 1130	<b>API 653 - Section 8 - Design Considerations for Reconstructed Tanks</b> General, New Weld Joints, Existing Weld Joints, Shell Design, Shell Penetrations, Wind Girders and Shell Stability, Roofs, Seismic Design



1230 - 1330	Lunch
1330 - 1500	<b>API 653 - Section 9 - Tank Repair And Alteration</b> General, Removal and Replacement of Shell Plate Material, Shell Repairs Using Lap-Welded Patch Plates, Repair of Defects in Shell Plate Material, 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, Repair of Fixed Roofs, Floating Roofs, Repair or Replacement of Floating Room Perimeter Seals, Hot Taps
1500 - 1515	Break
1515 - 1545	<b>API 653 - Section 10 - Dismantling And Reconstruction</b> General, Cleaning and Gas Freeing, Dismantling Methods, Reconstructions, Dimensional Tolerances
1545 - 1615	<b>API 653 - Section 11 - Welding</b> Welding Qualifications, Identification and Records
1615 - 1645	<b>API 653 - Section 12 - Examination And Testing</b> Nondestructive Examination, Radiographs, Hydrostatic Testing, Leak Tests, Measured Settlement During Hydrostatic Testing
1645 - 1700	<b>API 653 - Section 13 - Marking And Recordkeeping</b> Nameplates, Recordkeeping, Certification
1700 - 1725	<b>API 653 - Appendices B - F</b>
1725 - 1735	Administer API 653 Section Quiz
1735 - 1745	Distribute Homework
1745	End of Day Two

**Day 3 : Monday 10<sup>th</sup> January 2005**

0730 - 0800	Review Homework Answers
0800 - 0830	<b>API 650 - Section 1 - Scope</b> General, Limitations, Compliance, Referenced Publications
0830 - 0900	<b>API 650 - Section 2 - Materials</b> General, Plates, Welding Electrodes
0900 - 0945	<b>API 650 - Section 3 - Design</b> Joints, Bottom Plates, Annular Bottom Plates, Shell Design, Shell Openings, Shell Attachments and Tank Appurtenances, Roofs, Wind Load on Tanks (Overturning Stability)
0945 - 1000	Break
1000 - 1030	<b>API 650 - Section 4 - Fabrication</b>
1030 - 1100	<b>API 650 - Section 5 - Erection</b> General, Details of Welding, Inspection, Testing and Repairs, Repairs to Welds, Dimensional Tolerances
1100 - 1145	<b>API 650 - Section 6 - Methods Of Inspecting Joints</b> Radiographic Method, Magnetic Particle Examination, Ultrasonic Examination, Liquid Penetrant Examination, Visual Examination





1145 - 1230	<b>API 650 - Section 7 - Welding Procedure &amp; Welder Qualifications</b> Definitions, Qualification of Welders
1230 - 1330	Lunch
1330 - 1345	<b>API 650 - Section 8 - Marking</b> Nameplates, Division of Responsibility, Certification
1345 - 1435	<b>API 650 - Appendices B - S</b>
1435 - 1445	<b>Administer API 650 Section Quiz</b>
1445 - 1500	Break
1500 - 1515	<b>API RP 575 - Section 1 - Scope</b>
1515 - 1530	<b>API RP 575 - Section 3 - Selected Nondestructive Examination (NDE) Methods</b> Ultrasonic-Thickness Measurement, Magnetic Floor Testing
1530 - 1600	<b>API RP 575 - Section 4 - Types Of Storage Tanks</b> General, Storage Tanks with Linings and/or Cathodic Protection, Storage Tanks with Leak Detection Systems, Low-Pressure Storage Tanks
1600 - 1615	<b>API RP 575 - Section 5 - Reasons For Inspection and Causes of Deterioration</b> Reasons for Inspection, Corrosion of Steel Tanks
1615 - 1625	<b>API RP 575 - Section 6 - Frequency Of Inspection</b>
1625 - 1715	<b>API RP 575 - Section 7 - Methods Of Inspection And Inspection Scheduling</b> External Inspection of In-Service Tanks, Foundation Inspection, Anchor Bolt inspection, Grounding Connection Inspection, Thickness Measurements, Caustic Cracking, Tank Bottoms, Inspection Scheduling, Inspection Checklists
1715 - 1730	Pose Thought Questions to Class for Group Discussion
1730 - 1735	Distribute Homework
1735	End of Day Three

**Day 4 : Tuesday 11<sup>th</sup> January 2005**

0730 - 0800	Review Homework Answers
0800 - 0805	<b>API RP 651 - Section 1 - Scope</b>
0805 - 0815	<b>API RP 651 - Section 3 - Definitions</b>
0815 - 0825	<b>API RP 651 - Section 4 - Corrosion of Aboveground Steel Storage Tanks</b> Introduction, Corrosion Mechanisms
0825 - 0830	<b>API RP 651 - Section 5 - Determination of Need for Cathodic Protection</b>
0830 - 0845	<b>API RP 651 - Section 6 - Methods of Cathodic Protection for Corrosion Control</b> Introduction, Galvanic Systems, Impressed Current Systems, Cathodic Protection Rectifiers



0845 - 0900	<b>API RP 651 - Section 7 - Design Of Cathodic Protection Systems</b> Barriers to Cathodic Protection, Tank Bottom Replacement, Impervious Membrane Lining, Effects of Impermeable Membrane Secondary Containment Systems
0900 - 0905	<b>API RP 651 - Section 8 - Criteria For Cathodic Protection</b>
0905 - 0915	<b>API RP 651 - Section 9 - Installation Of Cathodic Protection Systems</b> Introduction, Galvanic Anode Systems, Impressed Current Systems
0915 - 0920	<b>API RP 651 - Section 10 - Interference Currents</b>
0920 - 0925	<b>API RP 651 - Section 11 - Operation and Maintenance of Cathodic Protection Systems</b>
0925 - 0930	<b>API RP 652 - Section 1 - Introduction</b>
0930 - 0935	<b>API RP 652 - Section 3 - Definitions</b>
0935 - 0945	<b>API RP 652 - Section 4 - Corrosion Mechanisms</b> Chemical Corrosion, Concentration Cell Corrosion, Corrosion Caused by Sulfate-Reducing Bacteria, Erosion-Corrosion in Water Treatment
0945 - 1000	<b>API RP 652 - Section 5 - Determination of The Need for Tank Bottom Lining</b> General, Design Considerations and Tank Internals, Tank History, Environmental Considerations, Flexibility for Service Change
1000 - 1015	Break
1015 - 1030	<b>API RP 652 - Section 6 - Tank Bottomlining Selection</b> General, Thin-Film Tank Bottom Linings, Thick-Film Tank Bottom Linings
1030 - 1040	<b>API RP 652 - Section 7 - Surface Preparation</b> General, Precleaning
1040 - 1045	<b>API RP 652 - Section 9 - Inspection</b>
1045 - 1100	<b>API RP 652 - Section 10 - Repair Of Tank Bottom Linings</b> General, Types of Repairs
1045 - 1100	<b>API RP 652 - Section 11 - Safety</b> Tank Entry, Manufacturer's Material Safety Data Sheets
1100 - 1110	Administer API RP 652 Section Quiz
1110 - 1115	<b>API 2207 - Section 1 - Introduction</b>
1115 - 1120	<b>API 2207 - Section 3 - Precautions</b>
1120 - 1125	<b>API 2207 - Section 6 - Safe Work Procedures</b>
1125 - 1130	Administer API 2207 Section Quiz
1130 - 1135	<b>API 2015 - Section 1 - General</b> Scope, Definitions
1135 - 1140	<b>API 2015 - Section 2 - Administrative Controls</b> General, Qualified Person
1140 - 1145	<b>API 2015 - Section 3 - Storage Tank Hazards</b> General, Oxygen Deficiency and Enrichment, Toxic Substances, Physical and Other Hazards



1145 - 1150	<b>API 2015 - Section 4 - Preparing the Tank for Entry and Cleaning</b>
1150 - 1155	<b>API 2015 - Section 5 - Testing The Tank Atmosphere</b> Oxygen Analyzers, Flammable Vapor Analyzers, Toxic Substance Indicators, Testing the Atmosphere
1155 - 1200	<b>API 2015 - Section 6 - Hazard Assessment for Entry Permits</b>
1200 - 1205	<b>API 2015 - Section 8 - Entering And Working Inside The Tank</b> Entry Permit, Attendant, Emergency Plan
1210 - 1215	<b>API 2015 - Section 9 - Hot Work And Tank Repairs</b> General, Hot Work Permit
1215 - 1225	<b>API 2015 - Appendices A - F</b>
1225 - 1230	Administer API 2015 Section Quiz
1230 - 1330	Lunch
1330 - 1430	<b>ASME Section V - Nondestructive Test Methods</b> Ultrasonic Thickness Testing, Liquid Penetrant Testing, Magnetic Particle Testing, Radiographic Film Interpretation
1430 - 1530	<b>ASME Section V - WPS and PQR requirements</b>
1530 - 1545	Break
1545 - 1615	<b>Review Procedure Exercise</b>
1615 - 1715	<b>ASME Section IX - Welder Certification</b>
1715 - 1720	Distribute Homework
1720	End of Day Four

**Day 5 : Wednesday 12<sup>th</sup> January 2005**

0730 - 0800	Review Homework Answers
0800 - 1000	<b>Question and Answer Session</b>
1000 - 1015	Break
1015 - 1230	<b>API 653 Sample Exam</b>
1230 - 1330	Lunch
1330 - 1530	<b>Review API 653 Exam Answers</b>
1530 - 1545	Break
1545 - 1600	Presentation of Certificates
1600	End of Course

**Course Coordinator**

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## **Section 1**

# **API 653 – Tank Inspection, Repair, Alteration, and Reconstruction**

## API - 653

### TANK INSPECTION, REPAIR ALTERATION AND RECONSTRUCTION

THIRD EDITION - DECEMBER 2001  
ADDENDUM 1 - SEPTEMBER 2003

#### SECTION 1 - INTRODUCTION

##### 1.1 General

1.1.1 This standard covers carbon and low alloy steel tanks built to API-650 and 12C standards. These standard provide **minimum** requirements for maintaining the integrity of welded or riveted, non-refrigerated, atmospheric pressure, above ground storage tanks **after they have been placed in service.**

##### 1.1.2 Scope coverage

Foundation, bottom, shell, structure, roof, attached appurtenances and nozzles to the face of the first flange, first threaded joint or first welded end connection.

**NOTES:**

1. Many API-650 requirements apply that will satisfy this new code.
2. In case of conflict (for in-service tanks) between API-12C; 650; and 653, **this latest Code governs.**

1.1.6 API 653 now recognizes API RP 579, Recommended Practice for *Fitness-for-Service*. Under API 653, the owner may use fitness-for-service criteria.

##### 1.2 Compliance

The owner/operator has ultimate responsibility for complying with API 653 provisions.

##### 1.3 Jurisdiction

Statutory Regulation (i.e., local, state or federal) shall govern, **unless** the requirements of this standard are **more stringent** than Statutory Regulation.

##### 1.4 Safe Working Practices

Safety procedures according to guidelines given in API publications 2015, 2016, and 2217A are suggested for potential hazards involved when conducting internal inspections, making repairs or dismantling tanks.

**NOTE:** Procedures must comply with any state or federal safety regulation involving "confined space" entry.

## SECTION 3 - DEFINITIONS

**3.1 alteration:** Any work on a tank involving cutting, burning, welding or heating operation that changes the physical dimensions and/or configuration of a tank. Typical examples of alterations include:

- a. The addition of manways and nozzles greater than 12-inch (NPS).
- b. An increase or decrease in tank shell height.

**3.2 applicable standard:** The original standard of construction, such as API standards or Underwriter Laboratories (UL) standards, unless the original standard of construction has been superseded or withdrawn from publication; in this event, applicable standard means the current edition of the appropriate standard. See Appendix A for background on editions of API welded storage tank standards.

**3.3 atmospheric pressure:** Used to describe tanks designed to withstand an internal pressure up to but not exceeding 2.5 lbs./sq. in. gauge.

**3.4 authorized inspection agency:** One of the following organizations that employ an Aboveground Storage Tank Inspector certified by API.

- a. The inspection organization of the jurisdiction in which the aboveground storage tank is operated.
- b. The inspection organization of an insurance company which is

licensed or registered to and does write aboveground storage tank insurance.

c. An owner or operator of one or more aboveground storage tank(s) who maintains an inspection organization for activities relating only to its equipment, and not for aboveground storage tanks intended for sale or resale.

d. An independent organization or individual under contract to and under the direction of an owner or operator and recognized or otherwise not prohibited by the jurisdiction in which the aboveground storage tank is operated. The owner or operator's inspection program shall provide the controls necessary for use by Authorized Inspectors contracted to inspect above ground storage tanks.

**3.5 authorized inspector:** An employee of an authorized inspection agency and is certified as an Aboveground Storage Tank Inspector per Appendix D of this standard.

**3.6 breakover point:** The area on a tank bottom where settlement begins.

**3.7 change in service:** A change from previous operating condition involving different properties of the stored product such as specific gravity or corrositivity and/or different service conditions of temperature and/or pressure.

**3.8 corrosion rate** The total metal loss divided by the period of time over which the metal loss occurred.

**3.9 critical zone:** The portion of the bottom or annular plate within 3 inches of the inside edge of the shell, measured radially inward.

**3.10 hot tap:** Identifies a procedure for installing a nozzle in the shell of a tank that is in service.

**3.11 inspector:** A representative of an organization's mechanical integrity department who is responsible for various quality control, and assurance functions, such as welding, contract execution, etc.

**3.12 owner/operator:** The legal entity having both control of and/or responsibility for the operation and maintenance of an existing storage tank.

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

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

**3.15 repair:** Any work necessary to maintain or restore a tank to a condition suitable for safe operation. Typical examples of repairs includes:

a. Removal and replacement of material (such as roof, shell, or bottom material, including weld metal) to maintain tank integrity.

b. Re-leveling and/or jacking of a tank shell, bottom, or roof.

c. Addition of reinforcing plates to existing shell penetrations.

d. Repair of flaws, such as tears or gouges, by grinding and/or gouging followed by welding.

**NOTE:** Alteration/Repair items may be closely related and could even be a matter of personal description (See also Section 12).

**3.16 repair organization:** An organization that meets any of the following:

a. An owner/operator of aboveground storage tanks who repairs or alters its own equipment in accordance with this standard.

b. A contractor whose qualifications are acceptable to the owner/operator of aboveground storage tanks and who makes repairs or alterations in accordance with this standard.

c. One who is authorized by, acceptable to, or otherwise not prohibited by the jurisdiction, and who makes repairs in accordance with this standard.

**3.17 storage tank engineer:** One or more persons or organizations acceptable to the owner/operator who are knowledgeable and experienced in the engineering disciplines associated with evaluating mechanical and material characteristics that affect the integrity and reliability of aboveground storage tanks. The storage tank engineer, by consulting with appropriate specialists, should be regarded as a composite of all entities needed to properly assess the technical requirements.

**3.18 external inspection:** A formal visual inspection, as supervised by an authorized inspector, to assess all aspects of the tank as possible without suspending operations or requiring tank shutdown (see 6.4.1).

**3.19 internal inspection:** A formal, complete inspection, as supervised by an authorized inspector of all accessible internal tank surfaces (see 6.4.1).

**3.20 fitness for service assessment:** A methodology whereby flaws contained within a structure are assessed in order to determine the adequacy of the flawed structure for continued service without imminent failure.



## SECTION 4 - SUITABILITY FOR SERVICE

### 4.1 General

4.1.1 When inspection indicates a change from original physical condition, evaluate to determine suitability for continued service.

4.1.2 **This section covers:**

- a. Evaluation for continued service.
- b. Decisions relative to repairs, alterations, dismantling, relocating, or reconstruction.

4.1.3 **Factors for consideration:** (plus engineering analysis and judgment)

- a. Internal corrosion (products or water bottom).
- b. External corrosion (environmental exposure).
- c. Allowable stress levels.
- d. Stored product properties (i.e., Specific Gravity, temperature, corrosivity).
- e. Metal design temperatures (at service location).
- f. External roof live load, wind and seismic loading.
- g. Foundation, soil and settlement conditions.
- h. Chemical analysis/mechanical properties (construction material).
- i. Existing tank distortions.
- j. Operating conditions (i.e., filling/emptying rates and frequency).

### 4.2 Tank Roof Evaluation (General)

4.2.1.2 Roof plates corroded to an average "t" of less than 0.09" (in any 100 sq. in) **Repair or Replace**.

#### 4.2.2 Fixed Roofs

Determine condition of roof support system (i.e., rafters, girders, columns, bases and out of plumb columns). Corrosion and/or damaged members - Evaluate for repair or renewal.

**NOTE:** Pipe columns require special attention. Severe internal corrosion **may not** be evidenced by external visual inspection.

#### 4.2.3 Floating Roofs

4.2.3.1 Cracks/punctures - Repair or replace.

4.2.3.2 Pitting/corrosion - Evaluate for potential penetration before the next scheduled internal inspection.

4.2.3.3 Roof support system, perimeter seals, drain system, venting, other appurtenances. Evaluate.

4.2.3.4 See API-650 (Appendix C and H) for evaluation guidance.

**NOTE:** Upgrading - **Not** mandatory to meet those guidelines on floating roofs.

#### 4.2.4 Change of Service

4.2.4.1 Internal pressure: Refer to API-650 (Appendix F) when evaluating/modifying roof or roof-to-shell junction.

4.2.4.2 External pressure: Roof support structure and roof-to-shell junction. Evaluate for effect of design partial vacuum. Refer to API-620.

4.2.4.3 All requirements of API-650 (Appendix M) shall apply before a change of service to operation at temperature above 200°F is considered.

4.2.4.4 See API-650 (or applicable standard) if operation is to be at lower temperature than original design.

4.2.4.5 Evaluate if change of service will effect normal or emergency venting.

### 4.3 Tank Shell Evaluation

4.3.1.1 Flaws, deterioration, (greater than CA) must be evaluated for continued use suitability.

4.3.1.2 The shell condition, analysis and evaluation shall take into consideration the anticipated loading conditions and combinations including:

- a. Pressure due to fluid static head.
- b. Internal and external pressure.
- c. Wind and seismic loads.
- d. Roof live loads.
- e. Nozzle, settlement and attachment loads.

4.3.1.3 Shell corrosion occurs in many forms and varying degrees of severity resulting in a generally uniform loss of metal over a large surface area or in localized areas. Pitting may also occur, but **does not** normally represent a significant threat to overall structural integrity unless present in a severe form with pits in close proximity to one another.

4.3.1.4 Methods for determining the minimum shell "t" suitable for continued operation are given in 4.3.2, 4.3.3, and 4.3.4. (see page 1-8 below for minimum shell "t" formula.)

### **4.3.2 Actual Thickness Determination**

This section deals with the averaging of corroded areas. This is not an exact science and should be used only when an area is questionable for repair. For exam purposes, you will be supplied with  $t_2$  and the diameter of the tank.

**Minimum Thickness Calculation for  
Welded Tank Shell  
(API 653 Section 4.3.3.1)**

$$t_{\min} = \frac{2.6 (H-1)DG}{SE}$$

$t_{\min}$  = the minimum acceptable thickness, in inches, for each course as calculated from the above formula; however,  $t_{\min}$  shall not be less than 0.1 inch for any tank course.

D = nominal diameter of tank, in feet.

H = height from the bottom of the shell course under consideration to the maximum liquid level when evaluating an entire shell course, in ft; or

height, from the bottom of the length L (see 4.3.2.1) from the lowest point of the bottom of L of the locally thinned area to the maximum liquid level, in ft; or

height from the lowest point within any location of interest to the maximum liquid level, in ft.

G = Highest specific gravity of the contents.

S = Maximum allowable stress in pounds per square inch; use the smaller of 0.80Y or 0.429T for bottom and second course; use the smaller of 0.88Y or 0.472T for all other courses. Allowable shell stresses are shown in Table 4-1 for materials listed in the current and previous editions of API Std. 12C and Std. 650. **Note:** For reconstructed tanks, S shall be per the current applicable standard.

Y = Specified minimum yield strength of the plate; use 30,000 psi if not known.

T = The smaller of the specified minimum tensile strength of the plate or 80,000 psi; use 55,000 psi if not known.

E = Original joint efficiency for the tank. Use **Table 4-2** if original E is unknown. E=1.0 when evaluating the retirement thickness in a corroded plate, when away from welds or joints by at least the greater of one inch or twice the plate thickness.

## FOR UNKNOWN MATERIAL

Maximum Allowable Stress (in PSI) Use the smaller of:

### *First or Second Course*

$$\begin{aligned} & \text{(Yield)} \\ & .80Y = .80 \times 30,000 = 24,000 \\ & \text{or} \\ & \text{(Tensile)} \\ & .429T = .429 \times 55,000 = 23,595 \end{aligned}$$

### *Other Courses*

$$\begin{aligned} & \text{(Yield)} \\ & .88Y = .88 \times 30,000 = 26,400 \\ & \text{or} \\ & \text{(Tensile)} \\ & .472T = .472 \times 55,000 = 25,960 \end{aligned}$$

**NOTE:** The Third Edition of API 653 has added a new table, Table 4-1, Maximum Allowable Shell Stresses (not for use for reconstructed tanks). This will make stress calculations much easier.

### Sample problem for minimum thickness of a welded tank shell.

An inspection of a welded, 138 foot diameter tank, 50 feet tall, 48 feet fill height shows some scattered pitting in the first course. What is the minimum shell thickness required for this tank, if the specific gravity of the product is 0.9?

$$t_{\min} = \frac{2.6 (H-1) DG}{SE}$$

$$\begin{aligned} t_{\min} &= ? \\ D &= 138' \\ H &= 48' \\ G &= .9 \\ S &= 23,600 \text{ (from Table 4-1)} \\ E &= 1 \end{aligned}$$

$$t_{\min} = \frac{2.6 (48-1)((138)(.9))}{23,600(1)}$$

$$\frac{15,177.24}{23,600}$$

$$t_{\min} = .643''$$

## Practice Problem

$$t_{\min} = \frac{2.6 (H-1) DG}{SE}$$

A 190' diameter tank has a pit that measures 5/16" deep in the first course, what is the min t, if the fill is 42 feet and the specific gravity is 0.6? (The pit is not in a weld seam or HAZ.) The material is unknown.

S = Maximum allowable stress in pounds per square inch; use the smaller of 0.80Y or 0.429T for bottom and second course; use the smaller of 0.88Y or 0.472T for all other courses.

Y = Specified minimum yield strength of the plate; use 30,000 psi if not known.

T = The smaller of the specified minimum tensile strength of the plate or 80,000 psi; use 55,000 psi if not known.

E = Original joint efficiency for the tank. Use **Table 4-2** if original E is unknown. E = 1.0 when evaluating the retirement thickness in a corroded plate, when away from welds or joints by at least the greater of one inch or twice the plate thickness.

## Explanation of Practice Problem

$$t_{\min} = \frac{2.6 (H-1) DG}{SE}$$

$$t_{\min} = ? \quad D = 190 \quad H = 42 \quad G = .6 \\ S = 23,600 \quad E = 1$$

$$t_{\min} = \frac{2.6 (42-1) (190) (.6)}{23,600(1)}$$

$$t_{\min} = \frac{12,152.4}{23,600}$$

$$t_{\min} = .515 \text{ inches}$$

The Exam recognizes a variation of the minimum thickness formula, even though the formula does not appear directly in the API 653 Standard. The calculation is for Maximum Allowable Fill Height based on a minimum thickness and can be found in the API 653 Body of Knowledge.

**Maximum Allowable Fill Height  
Calculation  
(API 653 Body of Knowledge)**

$$H = \frac{S \times E \times t_{\min}}{2.6 \times D \times G}$$

$t_{\min}$  = The minimum acceptable thickness, in inches, as calculated from the above formula; however,  $t_{\min}$  shall not be less than 0.1 inch for any tank course.

D = Nominal diameter of tank, in feet.

H = Height, in feet, from the bottom of the length L for the most severely corroded area in each shell course to the maximum design liquid level.

G = Highest specific gravity of the contents.

S = Maximum allowable stress in pounds per square inch; use the smaller of 0.80Y or 0.429T for bottom and second course; use the smaller of 0.88Y or 0.472T for all other courses.  
Note: For reconstructed tanks, S shall be per the current applicable standard.

Y = Specified minimum yield strength of the plate; use 30,000 psi if not known.

T = The smaller of the specified minimum tensile strength of the plate or 80,000 psi; use 55,000 psi if not known.

E = Original joint efficiency for the tank. Use Table 4-2 if original E is unknown. E=1.0 when evaluating the retirement thickness in a corroded plate, when away from welds or joints by at least the greater of one inch or twice the plate thickness.

**Note:** *The + 1 was removed from this formula because of a change in the base formula in API 653, Second Edition, Second Addenda. The API Body of Knowledge has not yet made the correction.*

### Sample problem for maximum allowable fill height of a welded tank shell.

An inspection of a welded, 138 foot diameter tank, 55 feet tall, shows some scattered pitting in the first course, minimum remaining thickness is .72". The product specific gravity is 0.9 What is the maximum fill height required for this tank?

$$H = \frac{S \times E \times t_{\min}}{2.6 \times D \times G}$$

$$H = ?$$

$$S = 23,600$$

$$E = 1$$

$$t_{\min} = .72''$$

$$D = 138'$$

$$G = .9$$

$$H = \frac{23,600(1) \times .72}{2.6(138)(.9)}$$

$$H = \frac{16,992.0}{322.92}$$

$$H = 52.620' \text{ or } 52' 6''$$

### Sample problem for maximum allowable fill height of a welded tank shell.

$$H = \frac{S \times E \times t_{\min}}{2.6 \times D \times G}$$

What is the fill height of a welded tank 112' diameter, that has a minimum thickness of .115 inches? The specific gravity of the product is .5

$$H = \frac{23,600 \times .115}{2.6 \times 112 \times .5}$$

$$H = \frac{2,714.0}{145.6}$$

$$H = 18.640' \text{ or } 18' 6\text{-}3/8''$$



The 3rd Edition of API 653 takes a two step approach for hydrostatic testing height  $H_t$ .

STEP A: Controlling Thickness

$$H_t = \frac{S_t E t_{\min}}{2.6D + 1}$$

STEP B: Locally Thinned Areas

$$H_t = \frac{S_t E t_{\min}}{2.6D}$$

**4.3.1.5** If the "t" requirements cannot be satisfied, the corroded or damaged areas shall be:

- a. Repaired, or
- b. Allowable liquid level reduced, or
- c. Tank retired.

**NOTE:** The maximum design liquid level shall not be exceeded.

**4.3.2 Actual "t" Determination:**

- a. See Inspection of Corrosion Areas (Fig. 4-1, Page 4-2).
- b. The controlling thickness in **each shell course**, where corroded areas of considerable size occur, must be determined.

**4.3.2.2 Widely scattered pits may be ignored if:**

- a. No pit results in the remaining shell "t" being less than one-half (1/2) of the minimum **acceptable** tank shell "t" (exclusive of the CA);  
**And**
- b. The sum (total) of their dimensions along any vertical line **does not** exceed two inches (2") in an eight inch (8") length. (See Fig. 4-2).

**EXAMPLE:**

Three (3) pits in close proximity. Dimension (measure) vertically - each pit. Add the sum (total dimensions) together.

$$* d_1 + d_2 + d_3 \dots \leq 2''$$

**NOTE:** If the pit dimension totals (measured vertically) **exceed** 2" in an 8" length, then these pits **must** be considered as strength factors.

**Special Note:**      Old method of evaluating pit problem.

1. Draw or imagine an 8" diameter circle.
2. Within the circle, measure all of the pit surface areas, individually.
3. Add all of the pit values together.  
\* **Unit of Measure = Sq. In.**
4. **If** the sum total of all the pit surface areas **exceed** 7 sq. in. within that 8" diameter circle, then the pits must be considered as strength factors.

#### 4.3.4 Minimum "t" calculation for Riveted Tank Shell

4.3.4.1 Use the same formula as 4.3.3.1, **except** that the following allowable stress criteria and joint efficiency shall be used:

- a.  $S = 21,000 \text{ lbs./sq./in.}$
- b.  $E = 1.0$  for shell plate 6" or more away from rivets.

**NOTE:** See Table 4-3 for joint efficiencies for locations within 6" of rivets.

4.3.4.3 Evaluate to what extent, if any, riveted joints have been affected by corrosion. Relate "bulging" condition between internal butt-straps and shell plates with stress placed on rivets.

### INTERNAL CORROSION - OBSERVATIONS/COMMENTS

Based on experience and personal observations **only**, the following is presented for field data survey and evaluation.

#### A. Tank Bottoms

1. For tanks with potential sour water present, check closely for accelerated corrosive attack around outer periphery. This is usually found at the lowest point and at the water collection point. Also applies to lower 4" - 6" of internal shell.
2. Some product services specifically attack weld seams and the adjacent HAZ
3. **Not Internal**, but related, corrosion often occurs to the underside of tank bottoms. If bottom leak is suspected as a result of underside corrosion, be prepared for a slow, long duration, expensive operation to verify and/or locate problem areas. \* Later reference under Bottom Evaluation.

## B. Tank Shells

1. See prior comment on lower shell area with potential for sour water attack. \* Sour Crude tanks very susceptible to this type corrosion.
2. The theory that the hot side (i.e., west side thermal input) is more corrosive has not been justified or verified.
3. Preferential attack on weld seams, HAZ, scaffold lug removal areas, etc., is not uncommon.
4. Extreme upper, non-wetted shell area often experiences accelerated corrosion. This is a very real possibility in sour crude or No. 6 fuel oils due to high sulfur content in the vapor phase.
5. Watch for accelerated metal loss (usually smooth, perhaps even grooved) at the normal product high liquid level in weak acid service.

## C. Tank Roofs/Support Structure

Should corrosion be found in the upper shell, the potential for a like loss should be suspected on the internal roof plates, the rafter/ structural members and the roof support columns. These specific areas are exposed to the same environment as the upper, non-wetted shell surface.

If only the two (2) lower shell rings show accelerated corrosion, closely check the roof support columns. Problems to the same degree and elevation may be present.

### 4.3.5 Distortions

4.3.5.1 Includes out-of-roundness, buckled areas, flat spots, peaking and banding at welded joints.

4.3.5.2 Potential causes:

- a. Foundation settlement
- b. Over or under-pressuring
- c. High winds
- d. Poor shell fabrication/erection
- e. Repair Techniques

### 4.3.6 Flaws cracks and laminations

- a. Examine/evaluate to determine need, nature or extent of repair. If repair is required, develop procedure (with sketch as necessary). Evaluate all issues on a case-by-case basis.
- b. Cracks in the shell-to-bottom (corner) weld are critical. **Removal**, not weld-over, is required.

### 4.3.9 Shell Penetrations

Consideration details include:

- a. Type and extent of reinforcement.
- b. Weld spacing.
- c. Proximity of reinforcement to shell weld seams.
- d. Thickness of component parts.
- e. Deterioration (internal/external).

## 4.4 Tank Bottom Evaluation

### 4.4.1 General

RBI is now a basis of this paragraph. All aspects of corrosion phenomena, all potential leak or failure mechanisms must be examined. Assessment period **shall be less** than or equal to the appropriate internal inspection interval.

**NOTE:** Excessive foundation settlement can have a serious impact on the integrity of shell and bottoms. Refer to Appendix "B" for tank bottom settlement techniques.

### 4.4.2 Causes of Bottom Leaks

Consider cause/effect/repair:

- a. Internal pitting.
- b. Corrosion of weld seams and HAZ
- c. Weld joint cracking.
- d. Stresses (roof support loads and settlement).
- e. Underside corrosion (i.e., normally pitting).
- f. Inadequate drainage.
- g. Lack of an annular plate ring, when required.
- h. Uneven settlement (with resultant high stress).
- i. Roof support columns (or other supports) welded to bottom without allowance for adequate movement.
- j. Rock or gravel foundation pads.
- k. Non-homogeneous fill under bottom (i.e., shell, rock, clay, wood stakes, etc.).
  - l. Inadequately supported sumps.

### 4.4.6 Bottom Measurements Methods (Appendix G may apply)

- a. Spot U. T. measurement.
- b. Visual, internal survey with hammer test.
- c. UT "B" scan.
- d. MFE or MFLT
- e. Section removal (i.e., coupon).
- f. Abrasive blast (scan for capillary wicking).

#### 4.4.7 Minimum "t" for Tank Bottom Plate

Two (2) Methods:

- a. **Deterministic** (See 4.4.7.1) - A long, drawn out formula/ data process. Not normally used.
- b. **Probabilistic** (See 4.4.7.2) - Normal process. Statistical analysis based on thickness data resulting from visual, mechanical or UT survey.

4.4.7.3 If the minimum bottom "t", **at the end** of the in-service period of operation, are calculated to be less than the bottom renewal thickness given in Table 6-1 (page 6-3), the bottom shall be repaired as follows: Lined, repaired, replaced or the interval to the next internal inspection **shortened**. Unless an RBI program is in place.

4.4.7.4 Critical zone thickness is redefined in this paragraph. Note the plate thickness in the critical zone shall be the smaller of 1/2 the original bottom plate thickness or 50% of t<sub>min</sub> of the lower shell course, but not less than 0.1 inch.

4.4.7.7 The bottom extension shall be no less than 0.1 inch thick and must extend beyond the outside toe of the shell-to-bottom weld at least 3/8 inch.

#### 4.4.8 Minimum "t" - Annular Plate Rings

1. See Visual Aide of Table 4-4 (page 4 - 9).
2. With product SG **less** than 1.0 that require annular plates for other than seismic loading consideration -- Also see Table 4-4.
3. SG **greater** than 1.0: Refer to Table 3-1 of the API-650 standard.

### 4.5 Tank Foundation Evaluation

#### 4.5.1 General - (causes of foundation deterioration):

- a. Settlement
- b. Erosion
- c. Cracking of concrete (i.e., calcining, underground water, frost, alkalies and acids).

#### 4.5.1.2 Description - concrete deterioration mechanisms.

- a. Calcining - (loss of water of hydration). Normally occurs when concrete has been exposed to high temperature for a period of time. During intermediate cooling periods, the concrete absorbs moisture, swells, loses its strength and cracks.
- b. Chemical attack: cyclic changes in temperature and by freezing moisture.
- c. Expansion in porous concrete caused by freezing moisture - Spalling or serious structural cracks.
- d. Concrete bond deterioration - Attack by sulfate-type alkalies or even chlorides.
- e. Temperature cracks (hairline with uniform width). **Not Normally** serious.\* Potential moisture entry points with resulting corrosion of the reinforcing steel.

#### 4.5.2 and 4.5.3 General

- a. For repair or renewal (See 10.5.6).
- b. Prevent water entry.
- c. Distortion of anchor bolts and excessive cracking of the concrete structure in which they are embedded may indicate:
  - (i) Serious foundation settlement.
  - (ii) Tank over pressure uplift condition.

## SECTION 5 - BRITTLE FRACTURE CONSIDERATIONS

### 5.1 General

Provides a procedure to assess the risk of failure due to brittle fracture, plus establishes general guidance for avoiding this type failure.

### 5.2 Basic Considerations

See Fig. 5-1 "Decision Tree" as the assessment procedure to determine failure potential. Prior incident data whereby brittle fracture has occurred either shortly after erection during hydrostatic testing or on the first filling in cold weather, after a change to lower temperature service, or after a repair/alteration. This failure has primarily occurred in welded tanks.

#### 5.2.1 Reported conditions involving failures (primarily involving welded tanks):

- a. Hydro test at initial erection.
- b. First filling in cold weather.
- c. After a change to lower temperature service.
- d. After a repair-alteration.

#### 5.2.2 Any change in service must be evaluated to determine if it increases the risk of failure due to brittle fracture. For example, the change to a more severe service involving one of the following:

- a. Lower operating temperature (especially below 60°F).
- b. Product with a higher specific gravity.  
\* Consider need for **hydrostatic test** when any repair or alteration **does not** meet **all** requirements of the 653 standard or deterioration of the tank has occurred since the original hydrostatic test.

#### General Comments:

1. Fracture assessment would most likely be conducted by a metallurgist or design specialist.
2. Several options exist based on the **most severe** combination of temperature and liquid level experienced by the tank during its life, whereby an **increased** potential for brittle fracture failure exists:
  - a. Restrict the liquid level.
  - b. Restrict the minimum metal temperature
  - c. Change service to a lower Specific Gravity. product.
  - d. A combination of the three areas listed above.
3. **Remember:** Reducing the storage temperature,- Increases the potential for failure. Shell stresses are increased and potential for failure is greater with a stored product change to a higher specific gravity.

## SECTION 6 - INSPECTION

### 46.1 General - In-service Inspection of Tanks

### 6.2 Inspection Frequency Considerations

#### 6.2.1 **Some** factors determining inspection frequency:

- a. Nature of stored product.
- b. Visual inspection/maintenance results.
- c. Corrosion rates and/or allowances.
- d. Corrosion prevention systems.
- e. Previous inspection results.
- f. Methods-materials of construction or repair.
- g. Tank location (i.e., isolated, grouped, high risk areas).
- h. Potential for air, water or soil pollution.
- i. Leak detection systems.
- j. Change in operating mode.
- k. Jurisdictional requirements.
- l. Changes in service (including water bottoms).
- m. The existence of a double bottom or a release prevention barrier.

6.2.2 The interval between inspections (internal/external) is most influenced by its service history, unless special reasons indicate an earlier inspection is required.

6.2.3 Local jurisdictional regulations (i.e., vapor loss values, seal condition, leakage, proper diking and repair procedures) should be known by inspection personnel in their **own** locality, or should be **furnished** by owner-user to inspectors who function at remote locations.

### 6.3 External Inspection (Routine In-Service Type)

#### 6.3.1.1 through 6.3.1.3

Routine external in-service inspection may be done by owner-user operator personnel. Routine requirements include:

- a. Visual inspection from the ground.
- b. Intervals shall not exceed one month.
- c. External check for leaks, distortion, settlement, corrosion, foundation, paint, insulation, etc.



## 6.3.2 Scheduled Inspections (All tanks)

6.3.2.1 Formal visual external inspection at least every five (5) years **or**  $RCA/4N$  years (where RCA is the difference between the measured shell thickness and the minimum required thickness in mills, and N is the shell corrosion rate in mills per year), whichever is less, by an Authorized Inspector. Tank may be in operation.

6.3.2.2 Remove insulation to extent necessary to determine condition of roof and shell.

6.3.2.3 Tank grounding system components, shunts, cable connection, etc., shall be visually checked.

6.3.2.4 Visually check tank grounding components.

## 6.3.3 In-service UT "t" measurement of shell.

6.3.3.1 Extent of UT survey - Determined by owner-user.

6.3.3.2 When UT is used as inspection method, intervals shall not exceed the following:

- a. Five (5) years from commissioning new tank.
- b. At five year intervals (existing tanks where corrosion rate is **not** known.
- c. When the corrosion rate **IS** known, the maximum interval shall be **the smaller** of  $RCA/2N$  years (where RCA is the difference between the measured shell thickness and the minimum required thickness in mils, and N is the shell corrosion rate in mils per year) **or** fifteen (15) years.

6.3.3.3 Internal tank shell inspection (out-of-service condition) can be substituted for a program of external UT measurements made during in-service condition.

6.3.4.1 Cathodic Protection System -- Survey in accordance with API RP 651.

## 6.4 Internal Inspection

### 6.4.1 General

Internal inspection is primarily designed to:

- a. Determine that bottom is not severely corroded or leaking.
- b. Gather data necessary to determine minimum "t" of shell and bottom for proper evaluation.

**NOTE:** Prior in-service UT data may be used as criteria in the assessment process.

- c. Identify/evaluate any tank bottom settlement.

**6.4.1.2** New item. The Authorized Inspector who is responsible for evaluation of a tank must visually examine each tank and review the NDE results.

### 6.4.2 Inspection Intervals

**6.4.2.1** Internal inspection intervals are determined by:

- a. Corrosion rates established during prior surveys.
- b. Anticipated corrosion rates based on experience with tanks in similar service.

**NOTES:**

1. Normally, bottom corrosion rates will control.
2. Set interval so that bottom plate **minimum "t"(at the next inspection) are not** less than the values listed in Tbl 6-1.
3. In **No** case, shall the internal inspection interval exceed **twenty** (20) years.

**6.4.2.2** If corrosion rates are **not known** and similar service data is not available (to determine bottom plate "t" at next inspection), the **actual** bottom "t" shall be determined by inspection(s), interval shall not exceed ten (10) years of operation to establish corrosion rates.

### 6.4.3 Alternative Internal Inspection Interval

For unique combinations of service, environment and construction, the owner/operator may establish the interval using an alternative procedure. This method includes:

- a. Determining bottom plate "t".
- b. Consideration of environmental risk.
- c. Consideration of inspection quality.
- d. Analysis of corrosion measurements.

As an alternative an RBI program may be used.

**NOTE:** Must be documented and made part of permanent record.

## 6.5 Alternative to Internal Inspection to Determine Bottom "t"

In cases where construction, size or other aspects allow **external access** to bottom, an external inspection (in lieu of internal) is allowed to meet requirements of Table 6-1. Documentation also required.

## 6.7 Inspection Checklists

Appendix "C" provides sample checklists of items for consideration for in or out-of-service inspections. A similar checklist also exists in API RP 575.

- NOTES:**
1. Would be very expensive and time consuming.
  2. Would require support personnel/equipment.
  3. Plant personnel could check a number of items.
  4. All are not necessary, unless special condition exists.

## 6.8 Records

### 6.8.1 General

- a. Records form the basis of **any** scheduled inspection/maintenance program. If no records exist, judgment may be based on tanks in similar service.
- b. Owner/operator must maintain a complete record file on each tank consisting of three (3) types:
  - i. Construction Records
  - ii. Inspection History
  - iii. Repair/Alteration History

### 6.8.2 Construction Records

May include the following:

- a. Nameplate information
- b. Drawings
- c. Specifications
- d. Construction completion report
- e. NDE performed
- f. Material analysis
- g. Hydro data

### 6.8.3 Inspection History

- a. Includes all measurements taken, condition of all parts inspected and a record of all examination and tests. Include a complete description of any unusual condition with probable reason for problem and recommendation for corrections.
- b. Sketches and detailed repair procedure should be provided if so desired by the customer.
- c. Corrosion rate and inspection interval calculations should be furnished and made a part of the permanent file.

### 6.8.4 Repair/Alteration History

Includes all data accumulated from initial erection with regard to repairs, alterations, replacements, plus data associated with service changes (i.e., specific gravity and temperature). Include results of coating-lining experience.

## 6.9 Reports

### 6.9.1 Recommended repairs shall include:

- a. Reason for the repair.
- b. Sketches showing location and extent.

### 6.9.2 General inspection reports shall include:

- a. Metal thickness measurements
- b. Conditions found
- c. Repairs
- d. Settlement data
- e. Recommendations

### 6.10 Non-Destructive Examinations

NDE personnel shall meet the qualifications identified in 12.1.1.2, but need not be certified in accordance with Appendix D. However, the results must be reviewed by an Authorized Inspector.

## SECTION 7 - MATERIALS

### 7.1 General

This section provides general requirements for materials when tanks are repaired, altered or reconstructed. (See Section 9 for specific data).

### 7.2 New Materials

Shall conform to current applicable tank standards.

### 7.3 Original Materials for Reconstructed Tanks

**7.3.1** All shell plates and bottom plates welded to the shell shall be identified. Original contract drawings, API nameplate or other suitable documentation do not require further identification. Materials not identified must be tested.(See 7.3.1.2.).

**7.3.1.2** If plates are not identified, subject plate to chemical analysis and mechanical tests, as required in ASTM-A6 and A370 (including Charpy V-Notch). API-650 impact values must be satisfied.

**7.3.1.3** For known materials, plate properties (at a minimum) must meet chemical and mechanical API-650 requirements with regard to thickness and design metal temperature.

**7.3.3** Flanges, fasteners, structural, etc., must meet current standards. Welding consumables must conform to the AWS classification that is applicable.

## SECTION 8 - DESIGN CONSIDERATIONS RECONSTRUCTED TANKS

### 8.2 New Weld Joints

- a. Must meet applicable standard.
- b. Butt-weld joint with complete fusion and penetration.

### 8.3 Existing Joints

Must meet original construction standard.

### 8.4 Shell Design

**8.4.1** When checking design criteria, the "t" for **each** shell course shall be based on measurements taken within 180 days prior to relocation.

**8.4.2** Determining maximum design liquid level for product is determined by:

- a. Calculate the maximum liquid level (each course) based on product specific gravity.
- b. Actual "t" measured for each course.
- c. Material allowable stress for each course. (See Table 3-2 - API-650).
- d. Selected design method.

### 8.5 Shell Penetrations

**8.5.1** New/replacement penetrations must be designed, detailed, welded and examined to meet current applicable standard.

**8.5.2** Existing penetrations must be evaluated for compliance with the original construction standard.

## SECTION 9 - TANK REPAIR AND ALTERATION

### 9.1 General

Basis for repair / alteration shall be equivalent to API-650 standard.

9.1.3 All repairs must be authorized by the Authorized Inspector or an engineer. The Authorized Inspector will establish hold points.

9.1.4 All proposed design, welding procedures, testing methods, etc., must be approved by the Authorized Inspector or an engineer.

9.1.5 Appendix F summarizes the requirements by method of examination and provides the acceptance standards, inspector qualifications, and procedure requirements. This is a good summary of NDT requirements and includes procedures from API 650, but it should not be used alone.

### 9.2 Removal and Replacement - Shell Plate

9.2.1 Thickness of the replacement shell plate shall not be less than the greatest nominal "t" of any plate in the same course adjoining the replacement plate **except** thickened insert plate.

**NOTE:** When evaluating plate suitability, any change from the original design condition (i.e., specific gravity, pressure, liquid level and shell height) must be considered.

#### 9.2.2 Minimum Dimensions of Replacement Shell Plate

9.2.2.1 Twelve inches (12"), **or 12** times the "t" of the replacement, whichever is greater.

**NOTE:** The replacement plate may be circular, oblong, square with rounded corners or rectangular with rounded corners, except when an entire plate is replaced. (See Fig. 9-1 for details).

9.2.2.2 When replacing entire shell plates, it is permissible to cut and reweld along the existing **horizontal** weld joints. Maintain weld spacing as per established API-650 values.

**NOTE:** **Prior** to welding the new vertical joints, the existing horizontal weld must be cut for a minimum distance of twelve inches (12") beyond the new vertical joints. As normal, weld verticals **before** roundseams.

## 9.2.3 Weld Joint Design

9.2.3.1 Replacement Shell Plates - Butt joints with complete penetration and fusion. Fillet welded lapped patch plates **are** permitted.

9.2.3.2 Weld Joint Design

- a. See API-650 (3.1.5.1 through 3.2.5.3).
- b. Joints in existing lap-weld shells may be repaired according to original construction standard
- c. Weld details - See API-650(5.2) and API-653 (Section 11).

9.2.3.3 Refer to Figure 9-1 for Minimum weld spacing dimensions.

**NOTE:** Special requirements for shell plates of unknown toughness, not meeting the exemption curve for brittle fracture: The new vertical weld must be at least 3" or 5T from bottom joints.

9.3.1 Lapped patch shell repairs are now an acceptable form of repair, API 653, Second Edition, Addenda 1. Existing patch plates may be evaluated to this Standard.

9.3.1.2 Lap patches may not be used on plate thicker than 1/2" or to replace door sheets.

9.3.1.3 Lap patch plates are not to be thicker than 1/2" or thinner than 3/16".

9.3.1.4 All lap patch plates may be circular, oblong, square, rectangular or meet the nozzle reinforcing plate shapes of API 650.

9.3.1.5 Lap patch plates may cross welds. See figure 9-1 for weld spacing details.

9.3.1.6 Lap patch plates may extend to and intersect with the external shell-to-bottom joint. Internal lap patches shall have 6" toe-to-toe weld clearance between the patch and the shell-to-bottom weld.

9.3.1.7 Maximum size of lap patch plates is 48" x 72", minimum 4".

9.3.1.8 Shell openings are not allowed within a lapped patch repair.

9.3.1.9 UT required in the areas to be welded, searching for plate defects and remaining thickness.



9.3.1.10 Repair plates shall not be lapped onto lap-welded shell seams, riveted shell seams, other lapped patch repair plates, distorted areas, or unrepaired cracks or defects.

9.3.2 Lapped patch plates may be used to close holes.

9.3.2.1 The lap patch plate must be seal-welded, including the inner perimeter of the hole. The minimum hole diameter is 2".

9.3.2.2 Nozzle necks and reinforcing plates shall be entirely removed prior to installation of a repair plate.

9.3.2.3 The overlap of a repair plate shall not exceed 8 times the shell thickness, minimum overlap is 1". The minimum repair plate dimension shall be 4 inches.

9.3.2.4 The repair plate thickness shall not exceed the nominal thickness of the shell plate adjacent to the repair.

9.3.3 Lapped patch plates may be used for thinning shells, below retirement thickness.

9.3.3.1 Full fillet weld required on lap patch plates.

9.3.4 Lapped patch repair plates may be used to repair small shell leaks or minimize the potential from leaks.

9.3.4.4 This repair method shall not be used if exposure of the fillet welds to the product will produce crevice corrosion or if a corrosion cell between the shell plate and repair plate is likely to occur.

9.3.4.5 This repair method shall not be used to repair shell leaks if the presence of product between the shell plate and repair plate will prevent gas freeing from the tank to perform hot work.

## 9.6 Repair of Defective Welds

9.6.1 Cracks, lack of fusion and rejectable slag/porosity require repair. Complete removal by gouging-grinding and the cavity properly prepared for welding.

9.6.2 Generally, it **is not** necessary to remove existing weld reinforcement in excess of that allowed in API-650.

9.6.3 Unacceptable weld undercut can be repaired by additional weld metal (or grinding), as appropriate.

**NOTE:** Maximum allowable depth of undercut:

- a. 1/64" on vertical seams
- b. 1/32" on horizontal seams

9.6.4 Weld joints that have experienced loss of metal by corrosion may be repaired by welding.

#### 9.6.5 Arc strikes

Repair by grinding or welded. If welded, grind flush.

### 9.7 Repair of Shell Penetrations

9.7.2 Reinforcing plates may be added but they must meet API-650 for dimensions and weld spacing.

9.7.3 Reinforcement plates can be installed to the inside wall, provided that sufficient nozzle projection exists for proper weld tie-in.

### 9.8 Addition/Replacement of Shell Penetrations

9.8.1 The December 1998 Addenda requires both API 653 and API 650 requirements be met for shell penetrations.

9.8.2 Penetrations larger than 2" NPS shall be installed with the use of an **insert** plate **if** the shell "t" is greater than 0.50" and the material **does not** meet the current design metal temperature criteria. Additionally, the minimum diameter of the insert plate shall be at least twice the diameter of the penetration or diameter plus twelve inches (12"), whichever is greater.

### 9.9 Alteration of Existing Shell Penetrations

9.9.1 Altered details must comply with API-650.

9.9.2 New bottom installation (above old bottom) and using the "slotted" method through the shell may **not now** meet spacing requirements. Options for alternate compliance include the following three (3) items:

9.9.2.1 Existing reinforcement plate may be "trimmed" to increase the spacing between the welds, provided the modification still meets API-650.

9.9.2.2 Remove existing reinforcement and install a new pad. "Tombstone" shapes are acceptable.

9.9.2.3 The existing penetration (nozzle and pad) may be removed and the entire assembly relocated to the correct elevation.

## 9.10 Repair of Tank Bottoms (Definition see paragraph 3.9)

9.10.1.1 See figure 9-5 for details for welded-on patch plates

9.10.1.2.1 No welding or weld overlays are permitted within the critical zone, except for welding of:

- a. Widely scattered pits.
- b. Pinholes
- c. Cracks in the bottom plates.
- d. Shell-to-bottom weld.
- e. Welded-on patch plates
- d. Replacement of bottom or annular plate.

9.10.1.2.4 If more extensive repairs are required within the critical zone (than as listed in 9.10.1.2.), the bottom plate (under the shell) shall be cut out and a new plate installed.

9.10.1.2.5 This is a new paragraph that gives the requirements for reinforcement plates.

**REVIEW NOTE:** Weld Spacing requirements must meet API-650 (3.1.5.4 and 3.1.5.5) requirements. No 3 plate laps closer than twelve inches (12") from each other, from the tank shell, from butt weld annular joints and from joints of the annular ring to normal bottom plates.

### 9.10.2 Replacement - Entire Bottom

9.10.2.1.1 Non-corrosive material cushion (i.e., sand, gravel or concrete) 3"-4" thick shall be used between the old and new bottoms.

9.10.2.1.2 The shell shall be "slotted" with a uniform cut made parallel to the tank bottom.

9.10.2.1.3 Voids in the foundation (below the old bottom) shall be filled with sand, crushed limestone, grout or concrete.

9.10.2.1.4 Raise elevation of existing penetrations if the new bottom elevation requires a cut through the reinforcement.

9.10.2.1.5 On floating roof tanks, keep in mind that the floating roof support legs may require revision to conform to new bottom elevation.

**9.10.2.1.6** New bearing plates are required for floating roof leg supports and for fixed roof support columns. Column length revisions are also required on fixed roof tanks.

**9.10.2.2** Consider removal of old bottom, or of providing protection from potential galvanic corrosion.

**NOTE:** See API-RP 651. Also see API-653 (4.4.5.) regarding bottom leak detection.

**9.10.2.3** New weld joints in the tank bottom or annular ring shall be spaced at least the greater of 3 inches or 5t from existing vertical weld joints in the bottom shell course.

### **9.10.3.1 Additional Welded-on Plates**

New inspection requirements, plates must be MT or PT if the weld spacing requirements can not be met.

## **9.11 Repair of Fixed Roofs**

### **9.11.1.1 and 9.11.2.2**

Same criteria as previously noted / discussed in API-650 relative to:

- a. Plate "t"
- b. Roof support structure
- c. Loading
- d. Roof-to-shell junction

## **9.12 External and Internal Floating. Roofs**

- a. Repair in accordance to original construction drawings.
- b. If no original drawings available, use criteria from API-650, Appendix C and H.

## **9.13 Repair/Replacement of Floating Roof Seals**

**9.13.1** Rim mounted seals can be removed, repaired or replaced. Items for consideration are:

- a. Minimize evaporation / personnel exposure by limiting seal segment removal to 1/4 of the seal at one time.
- b. Use temporary spacers to keep roof centered.
- c. In-service repair may be limited to seal component parts or high positioned vapor seals.

**9.13.2** Secondary seals can normally be "in-service" repaired or replaced.

### 9.13.3 Seal-to-Shell Gap

Corrective action includes:

- a. Adjusting hanger system or primary shoe seal types.
- b. Adding foam filler to toroidal seals.
- c. Increasing length of rim mounted secondary seals.
- d. Replacement (all or part) of the primary system.
- e. Adding a rim extension to install secondary seal.

### 9.13.4 Mechanical Damage: Repair or replace.

**NOTE:** Buckled parts require replacement, not straightening.

9.13.6 Minimum Allowable roof rim "t" = 0.10"  
Minimum "t" of new rim plate = 0.1875"

## 9.14 Hot Taps

Installation on existing in-service tanks with shell material that **does not** require post-weld heat treatment.

**NOTE:** Connection size and shell "t" limitations are:

- a. Six inches (6") and small-minimum shell "t" 0.1875"
- b. Eight inches (8") and smaller-minimum shell "t" 0.25"
- c. Fourteen inches (14") and smaller-minimum shell "t" 0.375"
- d. Eighteen inches (18") and smaller-minimum shell "t" 0.50"

9.14.1.2 Use low hydrogen electrodes.

9.14.1.3 Hot taps **are not** permitted on:

- a. Tank roof
- b. Within the gas/vapor space of a tank.

### 9.14.2 Hot Tap Procedure Requirements

- a. Use customer/owner developed-documented procedure.
- b. If no documentation is available, API Pub. 2201 applies.

### 9.14.3 Preparatory Work

9.14.3.1 Minimum spacing in **any** direction (toe-to-toe of welds) between the hot tap and adjacent nozzles shall be equivalent to the square root of RT (where "R" is tank shell radius, in inches, and "T" is the shell plate "t", in inches).

9.14.3.2 Shell plate "t" shall be taken in a minimum of four (4) places along the circumference of the proposed nozzle location.

#### 9.14.5 Installation Procedure

9.14.5.1 Pre-cut pipe nozzle to shell contour and outside bevel for full penetration weld. (See Fig. 9-6, page 9-12 for details).

9.14.5.2 After pipe nozzle is welded, install the reinforcement (1 piece or 2 pieces). A two piece pad requires a horizontal weld).

**NOTES:**

1. Full penetration weld - pad to nozzle.
2. Limit weld heat input as practical.

9.14.5.3 Upon weld completion:

- a. Conduct NDE as required by procedure.
- b. Pneumatically test per API-650 procedure.
- c. After valve installation, pressure test (at least 1.5 times the hydrostatic head) the nozzle **prior** to mounting the hot-tap machine.

9.14.5.4 Following the hot-tap machine manufacturer's procedure, **only** qualified operators can make the shell cut.

## SECTION 10 - DISMANTLING AND RECONSTRUCTION

### 10.1 General

10.1.1 Provides for dismantling and reconstruction of existing welded tanks relocated from their original site.

10.1.2 See Section 12 for hydrostatic and weld requirements.

### 10.3 Dismantling Methods

Cut into any size pieces that are readily transportable to new site.

#### 10.3.2 Bottoms

10.3.2.1 Deseam lapwelds, or cut alongside existing seams (a minimum of 2" from existing welds), except where cuts cross existing weld seams.

10.3.2.2 If **most** of the bottom is to be reused, cut from shell along line A-A (Fig. 10-1), or if **entire** bottom is salvaged **intact**, cut shell along line B-B.

#### 10.3.3 Shells

10.3.3.1 Cut shell by one, or a combination, of the following methods:

- a. Cuts made to remove existing welds and HAZ, the minimum HAZ to be removed will be one-half of the weld metal width or 1/4 inch, which ever is less, on both sides of the weld seam.
- b. Any shell ring 1/2 inch thick or thinner may be dismantled by cutting through the weld without removing the HAZ.
- c. Cuts made a minimum of 6" away from existing weld seams, except where cuts cross existing welds.

10.3.3.2 Shell stiffeners, wind girders and top angles may be left attached to shell or cut at attachment welds. If temporary attachments are removed, grind area smooth.

10.3.3.3 Cut shell from bottom plate along line B-B (see Fig. 10-1). The existing shell-to-bottom weld connection **shall not** be reused **unless** the entire bottom is to be salvaged intact.

### 10.3.4 Roofs

10.3.4.1 Cut roof by lapweld deseaming or alongside (a minimum of 2" from) the remaining welds.

10.3.4.2 Roof structure

Remove bolts or deseaming at structural welds.

### 10.3.5 Piece Marking

10.3.5.1 Shell bottom and roof plates

Mark prior to dismantling for ready identification and reconstruction placement.

10.3.5.2 Punch mark (minimum 2 sets) at matching centers located on top and bottom edges of each shell segment for future proper alignment.

## 10.4 Reconstruction

10.4.2.1 Welding notes as follows:

- a. Vertical weld joints should not be aligned with joints located in bottom plates.
- b. No welding over heat affected zones (from original tank welds), except where new joints cross original joints.
- c. Refer to Fig. 9-1 for weld spacing.

10.4.2.2 Tank and Structural Attachment Welding

Use processes specified in API-650.

10.4.2.3 Specific welding notes:

- a. **No** welding is allowed when parts to be welded are wet from rain, snow or ice or when rain or snow is falling, or during high wind conditions (unless the work is shielded). Caution this is a common practice and should be avoided.
- b. **No** welding is permitted when the base metal is below 0°F.
- c. If the base metal temperature is between 0° and 32°F **or** the metal "t" is in excess of 1", the base metal within 3" of welding shall be pre-heated to approximately 140°F.



10.4.2.4 As normal, each layer of weld deposit is to be cleaned of slag or other deposits.

10.4.2.5 As in API-650, the maximum acceptable undercutting is 1/64" for vertical butt joints and 1/32" for horizontal butt joints.

10.4.2.7 Same tack weld provisions as API-650, i.e.:

- a. Vertical , manual tacks - Remove.
- b. Vertical, submerged tacks - If sound, clean only.

**NOTE:** Tack welds left in place must have been applied by a qualified welder.

10.4.2.8 If weldable primer coatings exist, they must be included in procedure qualification tests.

**NOTE:** **All other** coating must be removed prior to welding.

10.4.2.9 Low-hydrogen electrodes required on manual metal-arc welds, including the shell to bottom attachment or annular plate ring.

### 10.4.3 Bottoms

10.4.3.2 Weld shell to bottom **first** (except for door sheets) before weldout of bottom plates is started.

### 10.4.4 Shells

10.4.4.1 Same fit-up/welding procedures and values as allowed in API-650 for **vertical** joints:

- a. Over 5/8" thick - misalignment shall not exceed 10% of "t" (maximum 0.125").
- b. Under 0.625" thick - misalignment shall not exceed 0.06".

**NOTE:** Complete vertical welding before roundseam below is welded.

#### 10.4.4.2 Horizontal joints

Upper plate shall not project over lower by more than 20% of upper plate "t"(with 0.125" maximum).

10.4.4.3 Material over 1.50" thick a minimum pre-heat of 200°F is required.

#### **10.4.5 Roofs**

There are no special stipulations, except that structural members must be reasonably true to line and surface.

### **10.5 Dimensional Tolerances**

**10.5.2.1** Allowable maximum out-of-plumbness (top of shell relative to shell bottom) shall not exceed 1/100 of total tank height, with a maximum of 5" this dimension also applies to roof columns.

#### **10.5.3 Roundness**

See values and measurement locations on Table 10-2.

#### **10.5.4 Peaking**

Shall not exceed 0.50".

#### **10.5.5 Banding**

Shall not exceed 1.00".

NOTE: Somewhat more lax than API-650.

#### **10.5.6 Foundations**

Same specifications as listed under API-650.

## SECTION 11 - WELDING

### 11.1 Welding Qualifications

- 11.1.1 Weld procedure specifications (WPS), welders and operators shall be qualified in accordance with Section IX of the ASME Code.
- 11.1.2 Weldability of steel from existing tanks must be verified. If the material specification is unknown or obsolete, test coupons for the procedure qualification shall be taken from the **actual** plate to be used.

## SECTION 12 - EXAMINATION AND TESTING

- 12.1.1.1 NDE shall be performed in accordance with API 650, plus API 653 supplemental requirements.
- 12.1.1.2 Personnel performing NDE shall be qualified in accordance with API 650.
- 12.1.1.3 Acceptance criteria shall be in accordance with API 650.

NOTE: Appendix "F" is not mentioned.

- 12.1.1.5 Appendix G is mentioned for qualifying personnel and procedures when using MFL.

### 12.1.2 Shell Penetrations

- 12.1.2.1 UT lamination check required for:
  - a. Adding reinforcement plate to an unreinforced penetration.
  - b. Installing a hot-tap connection.
- 12.1.2.2 Cavities from gouging or grinding to remove reinforcement pad welds require either a magnetic particle or liquid penetrant test.
- 12.1.2.3 Completed welds attaching nozzle to shell or pad to shell and nozzle neck shall be examined by a magnetic particle or liquid penetrate test. Consideration should be given for extra NDE on hot taps.
- 12.1.2.4 Complete welds in stress relieved components require magnetic particle or liquid penetrate testing (after stress relief, but before hydrostatic test).

### 12.1.3 Repaired Weld Flaws

- 12.1.3.1 Cavities from gouging or grinding to remove weld defects shall be either a magnetic particle or liquid penetrate tested.
- 12.1.3.2 Completed repair of **butt welds** shall be examined over their **full length** by UT or radiographic methods.

### 12.1.4 Temporary and Permanent Attachments to Shell Plates

- 12.1.4.1 A ground area resulting from the removal of attachments requires a visual test.
- 12.1.4.2 Completed welds on permanent attachments shall be examined by MT or PT, groups IV-VI, excluding the shell to bottom weld.

### 12.1.5 Shell-to-Shell Plate Welds

New welds attaching shell plate to shell plate require visual and radiographic examination. Additionally, plate greater than 1", the back-gouged surface of root pass and final pass (each side) shall be examined over its full length by a magnetic particle or liquid penetrate test.

- 12.1.5.2 New welds on new shell plate to new shell plate are to be examined and radiographed to API 650.

### 12.1.6 Shell-to Bottom

- 12.1.6.1 Joints shall be inspected over its entire length by a right angle vacuum box and a solution film, or by applying light diesel oil. ("Diesel" test technique).
- 12.1.6.2 An air pressure test may be used to check the shell-to-bottom weld.
- 12.1.8.2 (New Paragraph) deals with lap welded shell patches.

## 12.2 Radiographs

Number and location - Same as API-650, **plus** the following additional requirements:

### 12.2.1.1 Vertical Joints

- a. New plate to new plate: Same as API 650.
- b. New plate to existing plate: Same as API 650, plus one (1) additional radiograph.
- c. Existing plate to existing plate: Same as API 650, plus one (1) additional radiograph.

### 12.2.1.2 Horizontal Joints

- a. New plate to new plate: Same as API 650.
- b. New plate to existing plate: Same as API 650, plus one (1) additional radiograph for each 50 feet of horizontal weld.
- c. Existing plate to existing plate: Same as API 650, plus one (1) additional radiograph for each 50 of horizontal weld..

### 12.2.1.3 Intersections

- a. New plate to new plate: Same as API 650.
- b. New plate to existing plate: Shall be radiographed.
- c. Existing plate to existing plate: Shall be radiographed.

12.2.1.4 Each butt-weld annular plate joint - Per API-650.

12.2.1.5 For reconstructed tanks 25 percent of all junctions shall be radiographed.

12.2.1.6 New and replaced shell plate or door sheet welds:

12.2.1.6.1 Circular - Minimum one (1) radiograph

12.2.1.6.2 Square or Rectangular:

One (1) in vertical, one (1) in horizontal, one (1) in **each** corner.

**NOTE:** All junctions between repair and existing weld shall be radiographed. If defects are found, 100% is required on weld repair area.

12.2.1.8 For penetrations installed using insert plates as described in 9.8.2, the completed butt welds between the insert plate and the shell plate shall be fully radiographed.

## 12.2.2 Criteria Acceptance

If a radiograph of an intersection between new and old weld detects unacceptable flaws (by current standards) the weld may be evaluated according to the original construction standard.

## 12.3 Hydrostatic Testing

- 12.3.1.1 A full hydrostatic test, held for 24 hours, is required on:
- a. A reconstructed tank.
  - b. Any tank that has had major repairs or alterations (See 12.3.1.2.) unless exempted by 12.3.2 for the applicable combination of materials, design and construction features.
  - c. A tank where an engineering evaluation indicates the need for the hydrostatic test.

### 12.3.1.2 Major Repair / Alteration

Operations that require cutting, addition, removal and/or replacement of annular plate ring, shell to bottom weld or a sizable shell segment. **Major** would therefore include:

- a. The installation of any shell penetration (beneath the design liquid level) larger than 12" or any bottom penetration within 12" of the shell.
- b. **Any** shell plate (beneath design liquid level) or any annular plate where the **longest** dimension of plate exceeds 12".
- c. The complete or partial ( more than "1/2 t" of the weld thickness) or more than 12" of vertical seams, or radial annular plate welds.
- d. New bottom installation if the foundation under the new bottom is not disturbed.
  1. The Annular ring remains intact
  2. The welding repair does not result in welding on the existing bottom within the critical zone.
- e. Partial or complete jacking of a tank shell.

### 12.3.2 Hydrostatic **not** Required Conditions

- 12.3.2.1 A full hydrostatic test of the tank is not required for major repairs and major alterations when:
- a. The repair has been reviewed and approved by an engineer, in writing.
  - b. The tank owner or operator has authorized the exemption in writing.

### 12.3.2.2 Shell Repair

12.3.2.2.1 Weld procedures for shell repair must include impact testing.

12.3.2.2.3 New requirements, new shell materials must API 650 7th edition or later, must meet requirements for brittle fracture, stress must not be more than 7,000 psi as calculated from the new formula given in this paragraph.

$$S = \frac{2.6 H D G}{t}$$

$S$  = shell stress in pounds per square foot

$H$  = tank fill height above the bottom of repairs or alteration in feet

$t$  = shell thickness at area of interest in inches

$D$  = tank mean diameter in feet

$G$  = specific gravity of product

12.3.2.2.5 New radiography requirements, the finished weld in the shell plates shall be fully radiographed.

12.3.2.2.8 A big change in this section, door sheets shall comply with the requirements for shell plate installation, except they shall not extend to or intersect the bottom-to-shell joint.

### 12.3.2.3 Bottom Repair Within the Critical Zone

12.3.2.3.1 Now allows UT to be used on annular plate butt welds

## 12.5 Measured Settlement (During Hydro)

12.5.1.1 When settlement is anticipated, the tank being hydro-tested must have a settlement survey.

### 12.5.1.2 Initial Settlement Survey:

With tank empty, using the number of bottom plate projections as elevation measuring points (N), uniformly distributed around the circumference.

**FORMULA:**  $N=D/10$

Where:

- a. N = minimum number of measurement points (not less than 8). The Maximum spacing between measurement points shall be 32 feet.
- b. D = tank diameter (in feet).

**NOTE:** See Appendix B for evaluation and acceptance.

### 12.5.2 Survey During Hydro

Measure at increments during filing and at 100% test level.

**NOTE:** Excessive settlement (per Appendix B) shall be cause to stop test, investigate and/or repair.



## SECTION 13 - MARKING AND RECORD KEEPING

**13.1.1** API-653 reconstructed tanks require nameplate with letters and numerals must be a minimum of 5/32" high. The following information is required

- a. Reconstructed to API-653.
- b. Edition/revision number.
- c. Year reconstruction completed.
- d. If known, the original applicable standard and original date.
- e. Nominal diameter
- f. Nominal height.
- g. Design specific gravity of product stored.
- h. Maximum permissible operating liquid level.
- i. Contractor's serial and/or contract number.
- j. Owner/operator identification number.
- k. Material for each shell course.
- l. Maximum operating temperature.
- m. Allowable stress used in calculations for each course.

**13.1.2** New nameplate

Shall be attached to the tank shell adjacent to existing nameplate.

### **13.2 Record keeping**

Tanks evaluated, repaired, altered or reconstructed to API-653 require the following owner/operator records:

- a. Component integrity evaluation, including brittle fracture considerations.
- b. Re-rating data (including liquid level).
- c. Repair and alteration considerations.

- 13.2.1.3** Additional support data including, but not limited to, information pertaining to:
- a. Inspections (including "t" measurements).
  - b. Material test reports/certifications.
  - c. Tests.
  - d. Radiographs (to be retained for at least one year).
  - e. Brittle fracture considerations.
  - f. Original construction data.
  - g. Location and identification (owner/operator number, serial number).
  - h. Description of tank (diameter, height and service).
  - i. Design conditions (i.e., liquid level, specific gravity, stress and loading).
  - j. Shell material and thickness (by course).
  - k. Tank perimeter elevations.
  - l. Construction completion record.
  - m. Basis for hydrostatic test exemption

### **13.3 Certification**

Documentation of reconstruction in accordance with API-653 is required. (See Fig. 13-2).

## **APPENDIX B**

### **EVALUATION OF TANK BOTTOM SETTLEMENT**

**B.1.1** Common methods to monitor potential problem:

- a. Initial settlement survey, at erection and hydro.
- b. Planned frequency, per soil settlement predictions
- c. For existing tanks (with no settlement history), monitoring should be based on visual observations and prior service history.

**B.1.2** Excessive settlement requires evaluation/interpretation of survey data. Tank should be emptied and releveling repair conducted.

**B.1.3** Correcting shell and bottom settlement problems include the following techniques:

- a. Localized bottom plate repair.
- b. Partial releveling of tank periphery.
- c. Major releveling of shell and bottom.

### **B.2 Types of Settlement**

**B.2.1** Elevation measurements around the circumference and across the tank diameter are the best method for evaluating shell and bottom settlement problems. Local depressions may require other techniques.

## **B.2.2** Shell Settlement Evaluation

Tank settlement results from either one or a combination of the following three (3) settlement components:

**B.2.2.1** Uniform settlement. May vary in magnitude, depending on soil characteristics. It is the **least severe** or threatening settlement problem. It **does not** introduce stress in tank structure, but does present a **potential** problem for piping, nozzles and attachments.

**B.2.2.2** Planar Tilt (rigid body tilting). Rotates the tank in a tilted plane. This tilt will cause an increase in the liquid level and an increase in the shell hoop\* stress. Can also cause binding of peripheral seals in a floating roof and inhibit roof travel. This may be visible in the form of elongation of top shell ring in floating roof tanks. Can affect tank nozzles that have piping attached to them.

**B.2.2.3** Differential Settlement (out of plane). Due to a tank shell being a rather flexible structure, non-planer configuration type settlement often occurs.

Potential Problems:

- a. Increased stress levels.
- b. Elongation of upper shell.
- c. Floating roof travel interference and potential seal damage or roof "hang-up".
- d. Development of shell flat spots.
- e. High nozzle/piping stress levels.

**B.2.2.4** Uniform and rigid body tilt can cause problems as noted, overall integrity of the shell and bottom are more likely to be impacted by differential settlement. Therefore, this type problem becomes very important to determine severity and evaluate properly.

Common approach for settlement survey:

- a. Obtain transit survey from the correct number of evenly spaced points.
- b. Determine magnitude of uniform and rigid body tilt from each point on tank periphery.
- c. Develop a graphic line point representation of the involved data.

**NOTE:** Develop values (showing elevation differences) by comparing transit measurement readings by use of provided decimal chart. A stress analysis method is now included in this paragraph.

**B.2.2.5** Refer to B.3.2 for method of determining acceptable settlement condition or values.

### **B.2.3 Edge settlement**

**B.2.3.1** Occurs when tank shell settles sharply around the periphery, resulting in deformation of the bottom plate near the shell junction. (See Fig. B-4 for pictorial view).

### **B.2.5 Localized Bottom Settlement (Remote from Shell)**

**B.2.5.1** Depressions/bulged that occur in a random matter, remote from shell.

**B.2.5.2** Acceptability dependent upon:

- a. Localized bottom plate stresses.
- b. Design/quality of lap welds.
- c. Void severity below the bottom plate.

**NOTES:**

1. Not normally seen as extreme problem.
2. When occurring, normally associated with new tank where no or insufficient load bearing soil test borings have been made.

## **B.3 Determination of Acceptable Settlement**

### **B.3.1 General**

Greater settlement may be acceptable in tanks with a successful service history than new construction standards allow. Each condition must be evaluated, based on service conditions, construction materials, soil characteristics, foundation design and prior service history.

### **B.3.2 Shell Settlement**

Determine the maximum out-of-plane deflection. The formula for calculating the maximum permissible deflection is shown on page B-4. Requires technical assistance.

## **B.4 Repairs**

If conditions beyond acceptable conditions are found, a rigorous stress analysis should be performed to evaluate the deformed profile, or repairs conducted. Various repair techniques are acceptable. (See Section 9.10 for helpful details).

Several new figures have been added to Appendix B, however the bases for the new figures and requirements have been challenged. There is no bases for the information in the figures.. The user is left to his own devices as how to use this information.

## **APPENDIX C**

### **CHECKLISTS FOR TANK INSPECTION**

Tables C-1 and C-2 are sample checklists illustrating tank components and auxiliary items that deserve consideration during internal/external inspections. Use these as guidance items only. Numerous items need not be checked by the inspector, but rather by plant personnel.

**Table C-1** (In Service Inspection checklist) includes 111 separate items.

**Table C-2** (Out-of-Service Inspection Checklist) includes 248 separate items.

## **APPENDIX D**

### **AUTHORIZED INSPECTOR CERTIFICATION**

This Appendix was rewritten in the 4th Addenda to API 653.

**D.1** Written exam. based on the 'current' API 653 Body of Knowledge.

**D.2** Educational requirements for the API 653 Authorized Inspector.

**D.5** Recertification requirements for the API 653 Authorized Inspector.

**D.5.3** The requirements for re-examination are listed, after two re-certifications, 6 years, each inspector shall demonstrate knowledge of revisions to API 653.

## **APPENDIX E**

### **TECHNICAL INQUIRIES**

This section is a listing of how to contact the API 653 committee. The Technical Inquiry Responses have also been listed, but are not a part of the exam. This information is useful in actual application of API 653.

## APPENDIX F

### NDE REQUIREMENTS SUMMARY

This section is a summary of the requirements for NDE personnel and procedures, API 650, ASME Section V and VIII, and ASNT are listed. This is a very good section that will be useful to the user.

## APPENDIX G

### QUALIFICATION OF TANK BOTTOM EXAMINATION PROCEDURES AND PERSONNEL

This appendix was established in the first addenda to edition three of API 653 and outlines procedure and qualifications for floor scanning,

#### G.2 Definitions

**G.2.1 essential variables:** Variables in the procedure that cannot be changed without the procedure and scanning operators being re-qualified.

**G.2.2 examiners:** Scanning operators and NDE technicians who prove-up bottom indications.

**G.2.3 bottom scan:** The use of equipment over large portions of the tank bottom to detect corrosion in a tank bottom. One common type of bottom scanning equipment is the Magnetic Flux Leakage (MFL) scanner.

**G.2.4 authorized inspection agency:** Organizations that employ an aboveground storage tank inspector certified by API (see 3.4).

**G.2.5 non-essential variables:** Variables in the procedure that can be changed without having to re-qualify the procedure and/or scanning operators.

**G.2.6 qualification test:** The demonstration test that is used to prove that a procedure or examiner can successfully find and prove-up tank bottom metal loss.

**G.2.7 scanning operator (or operator):** The individual that operates bottom-scanning equipment.

**G.2.8 sizing (or prove-up):** The activity that is used to accurately determine the remaining bottom thickness in areas where indications are found by the bottom scanning equipment. This is often accomplished using the UT method.

**G.2.9 tank bottom examination:** The examination of a tank bottom using special equipment to determine the remaining thickness of the tank bottom. It includes both the detection and prove-up of the indications. It does not include the visual examination that is included in the internal inspection.

**G.2.10 tank bottom examination procedure (TBP):** A qualified written procedure that addresses the essential and non-essential variables for the tank bottom examination. The procedure can include multiple methods and tools, i.e., bottom scanner, hand scanner, and UT prove-up.

**G.2.11 tank bottom examiner qualification record (TBEQ):** A record of the qualification test for a specific scanning operator. This record must contain the data for all essential variables and the results of the qualification test.

**G.2.12 tank bottom procedure qualification record (TBPQ):** A record of the qualification test for a tank bottom examination procedure. This

record must contain the data for all essential variables and the results of the qualification test.

**G.2.13 variables or procedure variables:** The specific data in a procedure that provides direction and limitations to the scanning operator. Examples include; plate thickness, overlap of adjacent bottom scans, scanning speed, equipment settings. ect.

- G.3 An explanation of Tank Bottom Examination procedures
- G.4 Requirements for Tank Bottom Examiners
- G.5 Qualification Testing, including test plates, standards and variables.

## API 653 CODE QUIZ

1. In case of conflict between API-12C, API-650 and API-653 standards involving "in-service" AST's, which of the three codes will govern?
  - a. API-12C
  - b. API-650
  - c. API-653
  
2. Which of the following have the ultimate responsibility for complying with API-653 standard provisions?
  - a. On-site Inspector
  - b. Contractor Involved
  - c. Owner/operator of equipment
  - d. Relevant State or Federal Agency
  
3. Internal pressures inside tanks may vary. Which of the following pressures represent the maximum amount and is still considered to be atmospheric storage?
  - a. 3 oz. psig
  - b. 1.0 lb. psig
  - c. 1.5 lb. psig
  - d. 2.5 lb. psig
  
4. What is the joint efficiency of a lap riveted joint with one (1) row of rivets?
  - a. 45%
  - b. 60%
  - c. 75%
  - d. 80%



5. All prior reported brittle fracture tank failures have occurred under which of the following conditions/situations?
  - a. Atmospheric temperature of 20°F or lower.
  - b. During a hydro test where the test water was 50°F or colder.
  - c. Shortly after erection, following a repair/alteration, first cold weather filling or change to lower temperature service.
  - d. Where a testing medium other than water was used.
  
6. When external UT "t" measurements are used to determine a rate of general, uniform corrosion (relevant to shell integrity) which of the following values **cannot** be exceeded?
  - a. 10 years maximum
  - b. 20 years maximum
  - c. 5 years (after commissioning), or at 5 year intervals (where corrosion rate is not known).
  - d. Five years or  $RCA/4N$ , whichever is more.
  
7. What primary factor determines the interval between internal and external inspections?
  - a. Jurisdictional regulations
  - b. Tank service history, unless special reasons indicate an earlier inspection is required.
  - c. Known (or suspected) corrosion activity of product.
  - d. Change of service to a product with a specific gravity 10% higher than prior stored product.
  
8. What is the **minimum** dimension for a shell ring replacement piece or segment?
  - a. The actual area requiring renewal, plus 6" on all four surrounding sides.
  - b. 12" or 12 times the "t" of the replacement plate, whichever is greater.
  - c. 10% of the individual ring segment involved.
  - d. 20% of the individual ring segment involved.

9. Which of the areas described below are considered to be the "**critical zone**" involving tank bottom repair?
- Within the annular ring, within 12" of shell, or within 12" of inside edge of annular plate ring.
  - Any area where 3-plate laps are located
  - Within 36" (measured vertically) from any shell penetration above.
  - Within 3" from the shell on the bottom plates
10. Select the **minimum** number of "t" measurements required (along the circumference of any proposed "hot-tap" nozzle location):
- One (1) on horizontal centerline (3" from edge) on each side of proposed shell opening cut.
  - Four (4)
  - Eight (8)
  - Establishment of both a minimum and average "t" over the entire nozzle installation area.
11. What type of contour cut (if any) and what degree of bevel (if any) is required on the nozzle "barrel" end that is to be joined to shell during a "hot-tap".
- No contour cut required, 30° outside bevel.
  - No contour cut required, 45° outside bevel.
  - Cut to shell contour and outside beveled for full penetration attachment weld.
  - No contour cut required. 1/8" corner radius (minimum).
12. When reconstructing tank shells with a material "t" exceeding 1.50", what minimum pre-heat is specified?
- No preheat required, if air temperature exceeds 70°F.
  - 200°F.
  - 225°F.
  - 300°F.

13. In re-erecting a tank shell, what length "sweep-board" and what are maximum allowable values for weld seam peaking?
- a. 0.50" (1/2") with 36" horizontal sweep board?
  - b. 0.25" (1/4") on verticals; 0.50" (1/2") on horizontal with 36" board
  - c. 0.75" (3/4") with 48" board.
  - d. 1.00" (1") with 48" board.
14. Welding procedure Specs (WPS) are established in Section 11 of API-653. Welders/operators must be **qualified** in accordance with which of the codes listed.
- a. AWS
  - b. Section V ASME
  - c. Section VIII ASME
  - d. Section IX ASME
15. API-653 (Section 12) requires **greater** radiographic examination of tank shell welds than does API-650. Relevant to **new** or **repaired** vertical joints in existing shell plates, how many radiographs are required?
- a. Twice those required by API-650.
  - b. API 650 requirements plus one (1) in every joint.
  - c. One (1) for each welder or operator involved on each ring.
  - d. Two (2) for each welder or operator involved on each ring for all plate thicknesses.

**The following information applies for questions 16 through 20 below:**

An internal inspection is performed on an aboveground storage tank 44 feet tall, 40 foot fill height, 112 feet diameter, light oil (specific gravity = 1) service, sand pad with a reinforced concrete ring wall foundation. There is one area of general corrosion on the north side of the shell 38 inches wide and 20 inches tall. (The tank was built to API 650, 7th Edition).

16. Calculate the minimum thickness for the first course based on product alone.
- a. 7/8"
  - b. 3/4"
  - c. 5/8"
  - d. 1/2"

17. Calculate the "L" length for an area of general corrosion found ten feet from the bottom on the north side of the shell,  $t_2 = .125$  inches.
- a. 3.7"
  - b. 10"
  - c. 13.84"
  - d. 40"
18. There are four pits lined vertically on the south side of the tank in the first course. The pits measure 1", 1.250", 1." and .500" in length along a vertical line 8" long. The pit depth is approximately 0.255" each.
- a. A repair is required.
  - b. Because of the vertical pits, no repair is required.
  - c. If the pit depth is only .130 inches the pits may be ignored.
  - d. Scattered pits may be ignored.
19. A bulge is found on the tank floor, the diameter of the bulge is 30 inches, what is the maximum permissible height for the bulge?
- a. 11.1"
  - b. .463"
  - c. .962
  - d. 1.11"
20. An area of edge settlement in the tank bottom 6 feet from the tank shell has sloped down and settled. The settlement measures 2 inches at the deepest point. The edge settlement area has bottom lap welds approximately parallel to the shell.
- a. A more rigorous stress analysis must be performed.
  - b. The area must be repaired.
  - c. Sloped edge settlement is usually no problem
  - d. The area should be documented and checked during the next inspection.

## API 653 CODE QUIZ

### ANSWER KEY

1. c {Paragraph 1.1.2 page 1-1}
2. c {Paragraph 1.2 page 1-1}
3. d {Paragraph 3.3 page 3-1}
4. a {Table 4-3 page 4-7}
5. c {Paragraph 5.2.1 page 5-1}
6. c {Paragraph 6.3.3.2 (b) page 6-1 and 6-2}
7. b {Paragraph 6.2.2 page 6-1}
8. b {Paragraph 9.2.2.1 page 9-1}
9. d {Paragraph 3.9 page 3-1}
10. b {Paragraph 9.14.3.2 page 9-11}
11. c {Paragraph 9.14.5.1 page 9-11}
12. b {Paragraph 10.4.4.3 page 10-3}
13. a {Paragraph 10.5.4 page 10-3}
14. d {Paragraph 11.1.1 page 11-1}
15. b {Paragraph 12.2.1.1 page 12-2}
16. d (1/2") {Paragraph 4.3.3 page 4-3}

$$t_{\min} = \frac{2.6 (H-1) DG}{SE}$$

$$t_{\min} = ? \quad D = 112 \quad H = 40 \quad G = 1 \\ S = 23,600 \quad E = 1$$

$$t_{\min} = \frac{2.6 (40-1) (112) (1)}{23,600}$$

$$t_{\min} = \frac{11,356.8}{23,600}$$

$$t_{\min} = .481 \text{ inches (rounded to } 1/2 \text{ inch)}$$

17. c

$$L = 3.7 \sqrt{Dt_2} \quad L = 3.7 \sqrt{(112)(.125)} \quad L = 3.7 \sqrt{\quad}$$

18. a (A repair is required.) Paragraph 4.3.2.2 Page 4-3  
 Add the pit diameters  $1'' + 1.25'' + 1'' + .500'' = 3.75''$  (More than allowed in an 8'' area)  
 The pit depth exceeds one-half the minimum acceptable tank shell thickness.

19. b (.463") (Paragraph B.3.3 Page B7)  
 $R = \text{Diameter divided by } 2, \text{ in feet, } 30'' \text{ divided by } 2 = 15'' \text{ divided by } 12 = 1.25 \text{ feet.}$   
 $B = .37R$   
 $B = .37 (1.25) \quad B = .463 \text{ inches}$

20. d (The area should be documented and checked during the next inspection.) Figure B-10  
 Using figure B-10 the area is acceptable, it should be documented.



## **Section 2**

### **API 650 – Welded Steel Tanks for Oil Storage**

## API STANDARD 650

### WELDED STEEL TANKS FOR OIL STORAGE

Tenth Edition, November, 1998

Addendum 1, January, 2000

Addendum 2, November, 2001

Addendum 3, September 2003

#### SECTION 1 - SCOPE

##### 1.1 General

**1.1.1** This standard covers material, design, fabrication, erection and testing requirements for vertical, cylindrical, aboveground, closed and open-top, welded steel storage tanks in various sizes and capacities for internal pressures approximating atmospheric pressure.

**NOTE 1:** This standard covers only tanks whose entire bottom is uniformly supported and only tanks in non-refrigerated service that have a maximum operating temperature of 200° F.

**NOTE 2:** A bullet (•) at the beginning of a paragraph indicates that there is an expressed decision or action required of the purchaser.

**APPENDIXES:** Listed below apply to specifics that most often apply to new tank erections whereby Inspector knowledge must be reasonably thorough.

**1.1.3** The purchaser will specify SI dimensions or US customary dimensions.

**1.1.6 Appendix B:** Design and construction of foundations under flat bottom oil storage tanks.

**1.1.7 Appendix C:** Requirements for pan-type, pontoon-type and double deck-type external floating roofs.

**1.1.12 Appendix H:** Requirements for an internal roof in a tank that has a fixed roof at the top of the tank shell.

**1.1.14 Appendix J:** Requirements covering the complete shop assembly of tanks not more than 20 feet in diameter.

**1.1.15 Appendix K:** An example of the application of the variable-design-point method to determine shell-plate thickness.

**NOTE:** In larger tanks (over 200 feet in diameter), use of higher tensile strength steel, plus increased NDE procedures reduces plate "t".

**1.1.17 Appendix M:** Requirements for elevated temperature product storage up



to 500° F.

**NOTE:** Appendixes A, D, E, F, L, N, O and P cover requirements on specifics that apply much less frequently from an inspection perspective.

**1.1.21 Appendix S:** Requirements for the construction of austenitic stainless steel tanks.

**1.1.22 Appendix T:** Requirements for inspection (summary).

**1.1.23 Appendix U:** Requirements for UT examination, in lieu of radiography.

## **1.2 Limitations**

- a. API 650 stops at the face of the first flange.
- b. API 650 stops at the first sealing surface.
- c. API 650 stops at the first threaded connection.
- d. API 650 stops at the first circumferential weld.

## **SECTION 2: MATERIALS**

### **2.1 General Material Requirements**

**2.2.1.1** Refer to 2.2.2 ASTM Standards for acceptable tank steel plate requirements.

**2.2.1.2** Plate for shells, roofs and bottoms may be on an edge-thickness basis or on a weight (pounds per square foot) basis. Example: 3/16" plate (0.1875" or 7.65 lbs.) or 1/4" plate (0.250" or 10.4 lbs.), etc.

**2.2.1.2.3** Whether an edge-thickness or a weight basis is used, an underrun of not more than 0.01" from the computed design thickness or the minimum permitted thickness is acceptable.

**NOTE:** Most common plates used:

1. ASTM A-283 Gr. C
2. ASTM A-36
3. Alternate Design Basis (ADB) tanks (See Appendix K) require higher tensile strength material.

**2.2.2** New ASTM specification used.

**2.2.8** Special plate requirement or testing:

- a. Customer may require a set of charpy v-notch impact specimens.
- b. Special toughness requirements may be specified.

**2.2.9.3** Normal design metal temperature shall be assumed to be 15°F above the lowest 1-day mean ambient temperature in the locality where the tank is to be installed. (See Fig. 2-2).

**2.2.9.4** Plate used to reinforce shell openings shall be of the same material as the shell plate to which it is attached.

**NOTE:** Also must be **at least** as thick as primary plate! Shell nozzles and manway materials shall be equal or greater yield and tensile strength and shall be compatible with the shell material.

**2.2.10.4** The manufacturer must furnish mill test data, including the required toughness at design metal temperature.

## **2.8 Welding Electrodes**

For welding materials with a minimum tensile strength less than 80 kips per square inch, manual arc-welding electrodes shall conform to the E60 and E70 series, AWS 5.1.

## **SECTION 3: DESIGN**

### **3.1 Joints (Tank Design)**

**3.1.1-3.1.1.8** No detailed discussion. Be knowledgeable about the eight (8) types listed.

**3.1.3.2** Tack welds **are not** considered as having any strength value in the finished structure.

**3.1.3.3** On plates 3/16" thick, a full fillet weld is required. On plates thicker than 3/16", the weld shall **not be less** than one-third the "t" of the thinner plate at the joint, with minimum of 3/16".

**3.1.3.4** Single lap welds - bottom and roof plates only.

**3.1.3.5** Lap-weld joints shall be lapped not less than "5t" of the thinner plate, but need not exceed 1".

**3.1.4** AWS weld symbols are required on drawings.

#### **3.1.5.2 Vertical Shell Joints**

- a. Verticals shall be butt joints with complete penetration and fusion that will provide the same quality of deposited metal on both outside and inside weld surfaces.
- b. Vertical joints (in adjacent shell courses) shall not be in alignment. An off-set from each other of "5t"(where "t" is the thickest course at the point of offset).

### 3.1.5.3 Horizontal shell joints

Same criteria as for verticals above, except that top angles may be double-lap welded.

### 3.1.5.4 Lap-welded Bottom Joints

- a. 3-plate laps shall not be closer than 12" from each other, from the tank shell, from butt-welded annular plate joints and from joints between annular plate and bottom.
- b. Welded on top side only (full fillet only).
- c. On other than annular (doughnut) rings the plate under the shell must have the outer end of the joint fitted and welded to form a smooth bearing for the shell plate. **Note:** Called a "**BREAK-OVER**." (Fig 3.3.b)

**NOTE:** When annular plates are used or required, **butt** welding is required with a **minimum** distance of 24" between shell and any bottom lap seam.

### 3.1.5.5 Butt-weld bottom joints (i.e., normally annular ring)

- a. Parallel edges - either square or v-grove beveled.
- b. If square, root opening not less than 1/4".
- c. Minimum 1/8" thick back-up strip required.
- d. A 12" minimum space from each other or tank shell also applies.

### 3.1.5.6 Annular ring joints - complete penetration and fusion

**NOTE:** A 2" minimum projection beyond outside edge of shell (i.e., bottom extension). See Par. 3.5.2).

### 3.1.5.7 Shell-to-Bottom Fillet Welds

- a. If shell is 1/2" thick or less - Fillets not more than 1/2" or less than the nominal "t" of the **thinner** plate joined.
- b. Two (2) weld passes (minimum) are required.

### 3.1.5.9 Roof and Top-Angle Joints

- a. Welded top side only with continuous full-fillet. Butt welds are also permitted.
- b. Top angle (horizontal leg) may extend either inside or outside.

### 3.2.5 Tank Capacity

Three new paragraphs that describe the requirements for stating the capacity for a new tank.

### 3.4 Bottom Plates

- a. A minimum nominal "t" of 1/4" (10.2 lbs. per sq. ft.), exclusive of any corrosion allowance (CA).
- b. A 1" minimum width to project beyond outside edge of shell, on lap weld bottoms (i.e., bottom extension).

### 3.5 Annular Bottom Plates

- a. Annular bottom plates must be 24 inches wide.
- b. A 2 inch projection beyond the outside of the shell.

### 3.6 Shell Design

Shell designed on basis that tank is filled to a level "H" (fill level) with a specific gravity (SG) product value furnished by customer.

**NOTE:** Normally designed to be filled with water (i.e., SG of 1.0).

**3.6.1.7** Manufacturer must furnish drawing that lists:

- a. Required shell "t" (including CA) for design product and hydro test.
- b. Nominal "t" used, (i.e.; shell "t" as constructed).
- c. Material specification.
- d. Allowable stresses.

**3.6.2** Allowable Stress - Be familiar with Table 3-2 for plate specifications, yield / tensile strength and stress involved.

**NOTE:** ASTM A-283, A-285 (GR. C.) and A-36 are the most common.

**3.6.3 One Foot Method** - Calculates the "t" required at design points 1 foot **above** the bottom of each shell course. **\*Not** allowed for shells greater than 200 feet in diameter.

**Formula:**  $t_d = \frac{2.6D(H-1)G}{S_d} + CA$  (Design Shell Thickness)

Formula:  $t_t = \frac{2.6D(H-1)}{S_t}$

**NOTE:** See 3.6.3.2 for details as to actual values or relationship of items shown in the formula above.

### 3.7 Shell Openings

3.7.1.6 Manway necks, nozzle necks and shell plate openings shall be uniform and smooth, with the corners rounded, except where the surfaces are fully covered by attachment welds.

**NOTE:** 1/8" corner radius for 2" and smaller nozzle.  
1/4" corner radius for larger nozzle sizes.

3.7.2.1 No reinforcement required for nozzles 2" and smaller.

3.7.2.2 By design, nozzle necks (i.e., outside extension, within the shell plate "t" and inside extension) **may** provide the necessary reinforcement.

**NOTE:** For manway and nozzle design values/fabrication details, be familiar with and able to select the proper values from the following data sheets:

1. Fig. 3-4A, 3-4B, 3-5 and 3-6.
2. Tables 3-3, 3-4, 3-5, 3-6, 3-7, 3-8, 3-9 and 3-10.

### 3.7.3 Spacing of Welds Around Connections

This paragraph and the next three paragraphs confuse the weld spacing issue. A great deal of confusion has been relieved with the addition of figure 3-22, minimum weld requirements for openings in shells according to section 3.7.3, see page 3-49.

3.7.4.2 Paragraphs on stress relief of materials.

3.7.4.5 Hold times for stress relieving temperatures.

### 3.8 Shell Attachments (i.e., surface items such as angles, clips and stair treads).

3.8.1.2 Permanent attachment welds shall not be closer than 3" from horizontal shell joint seams, nor closer than 6" from vertical joints, insert-plate joints or reinforcement-plate fillet welds.

3.8.5 Roof Nozzles - See Fig. 3-12, 3-13 and 3-14.

**NOTE:** Remember note on bottom of Fig. 3-14. "When the roof nozzle is used for **venting**, the neck shall be trimmed flush with the roof line".

3.9.6 Primary/Secondary Wind Girders or Stiffeners:  
**and**

3.9.7 See Fig. 3-17 for typical stiffening ring sections.

**NOTE:** Intermediate wind girders cannot be attached within 6" of a horizontal shell joint.

## 3.10 Roofs

3.10.1 Refer to fixed roof types.

3.10.2.1 Roofs and structure designed to support dead load (i.e., roof deck and appurtenances), plus a uniform live load of not less than 25 lbs. per sq. ft. of projected area.

3.10.2.2 Roof plates - minimum nominal "t" of 3/16" (7.65 lbs. per sq. ft., 0.180" plate or 7 gauge sheet).

**NOTE:** Self-supported roofs may require thicker plate.

3.10.2.3 Supported cone roof plates **shall not** be attached to the supporting members.

3.10.2.4 Internal-External structural members must have a minimum nominal "t" (in any component) of 0.17".

3.10.2.5 Roof plate weld attachment to top angle.

**NOTE:** Refer to Glossary, Frangible Joint, Items "a, b and c" -See weld size restrictions/conditions. (3/16")

3.10.2.6 Frangible roof general information.

3.10.2.7 Roof plates may be stiffened by welded sections, but not connected to girders-rafters.

3.10.4.1 Supported cone roofs slope 3/4" in 12" (or greater).

3.10.4.4 Rafters shall be spaced so that in the outer ring, their centers **are not more** than 2 π ft. (6.28 feet), measured along the circumference. The maximum spacing for inner ring rafters (i.e., "Jack" rafters) is 5.5 feet.

**NOTE:** In earthquake zones, where specified, 3/4" diameter tie rods (or equivalent) shall be placed between the outer ring rafters (i.e., "Long" rafters). Not necessary if "I" or "H" sections are used as rafters.

3.10.4.5 **Roof Columns**

Structural shapes or steel pipe is acceptable. If pipe, it must be sealed (or provisions for draining or venting made).

#### 3.10.4.6 Rafter and Column Base Clips

- a. Outer row rafter clips - welded to tank shell.
- b. Column-base clip guides - welded to tank bottom to prevent lateral shift.
- c. Other structural attachments - welded, bolted or riveted.

### 3.11 Wind Load on Tanks (Overturning Stability)

3.11.1 Where specified, overturn stability values are and the wind load (or pressure) shall be assumed to be:

- a. Vertical plane surfaces - 30 lbs. per sq. foot.
- b. Projected areas - Cylindrical surfaces - 18 lbs.
- c. Conical-double curved surfaces - 15 lbs.

**NOTE:** All based on wind velocity of 100 m.p.h.

3.12.3 Anchor spacing - maximum of 10 feet apart.

## SECTION 4 - FABRICATION

### 4.1 Fabrication (General)

4.1.1.2 When material requires straightening:

- a. Pressing or non-injurious method required (prior to any layout or shaping).
- b. Heating or hammering not permitted, unless heated to a forging temperature.

## SECTION 5 - ERECTION

### 5.1 Erection (General)

5.1.1 Subgrade shall be uniform and level (unless otherwise specified) i.e., sloped (1 way) bottoms.

5.1.5 Erection lugs shall be removed, noticeable projections or weld metal removed, torn or gouge areas repaired.



## 5.2 Welding (General)

### 5.2.1.1 Acceptable weld processes

- a. Shielded metal-arc
- b. Gas metal-arc
- c. Flux-cored arc
- d. Submerged-arc
- e. Electroslag
- f. Electrogas

May be performed manually, automatically or semi-automatically. Complete fusion with base metal required.

**NOTE:** Procedures described in ASME Section IX.

### 5.2.1.2 Welding prohibited when:

- a. Surfaces are wet or moisture falling on surfaces.
- b. During high winds (unless shielded).
- c. When base metal temperature is less than 0° F.
- d. Base metal temperature is between 0° - 32° F and "t" exceeds 1 1/4" pre-heat of metal within 3" of weld is required.

5.2.1.3 Multilayer welds require slag and other deposit removal before next layer applied.

5.2.1.4 All weld edges must merge with plate surface without a sharp angle.

- a. Maximum acceptable undercut - 1/64" (0.016") vertical butt joints.
- b. Maximum acceptable undercut - 1/32" (0.031") horizontal butt joints.

5.2.1.8 Tack welds, used in vertical joints, **shall be** removed and not remain in finished joint - **when manually welded**. If sound, cleaned and fused, tack welds can remain when the submerged-arc process is used.

5.2.1.10 Low-hydrogen electrodes shall be used for manual metal-arc welds, including shell to bottom junction for all shell courses over 0.5" thick of Group I-III material.

5.2.1.11 Stud welding is recognized.

## 5.2.2 Bottoms

5.2.2.2 After layout/tacking, weld out may proceed with some shrinkage seams left open.

- 5.2.2.3 Shell to bottom welding shall be practically completed, before shrinkage openings (in 5.2.2.2. above) are welded.
- 5.2.3 Shells
- 5.2.3.1 Misalignment in completed vertical joints over 5/8" thick, shall not exceed 10% of plate "t", with a maximum of 0.125". Misalignment in completed vertical joints 5/8" thick and less thick shall not be greater than 0.06".
- 5.2.3.3 The reverse side of double-welded joints (**prior** to the application of the first bead to the second side), must be cleaned by chipping, grinding or melting out.
- 5.2.3.4 Joints exceeding 1 1/2" base metal "t"
- a. **No** pass over 3/4" thick is permitted.
  - b. Minimum preheat of 200°F is required.
- 5.2.3.5 New requirement for a procedure that minimizes the potential for underbead cracking, in group IV through VI material.
- 5.2.3.6 After any stress relief (but before hydro), welds attaching nozzles, manways and cleanout openings shall be visually and magnetic particle or die penetrant tested.
- 5.2.4.1 Shell-to-bottom welds, inside, may be checked by visual and any of the following: magnetic particle, PT solvent, PT water washable, diesel test or right angle vacuum box.
- 5.2.4.2 New paragraph, a new procedure as an alternative to paragraph 5.2.4.1, allows for pressure testing the volume between the inside and outside welds to 15 psi and applying a soap solution to the face of the fillet welds.

### 5.3 INSPECTION, TESTING, AND REPAIRS

5.3.2.1 Butt welds, must be inspected visually, radiographic or ultrasonic method.

5.3.3 Examination and testing of the tank bottom:

- a. Vacuum box
- b. Tracer gas test
- c. External "float" test

**NOTE:** Vacuum text procedure removed from this paragraph. The procedure is now in paragraph 6.6, as well as a procedure for tracer gas testing.

5.3.5 Reinforcing pads tested by up to 15 PSIG pneumatic pressure between tank shell and reinforcement on each opening.

5.3.6 Shell Testing - Be familiar with procedure.

#### 5.4 Weld Repair

5.4.2 Pinhole or porosity bottom leaks - weld over.

5.4.3 All defects in shell or shell-to-bottom joints.

NOTE: See Specifics - 6.1.7.

#### 5.5 Dimensional Tolerances

The maximum out-of-plumbness of the top (relative to bottom of shell) may not exceed 1/200 of the total tank height.

5.5.2 The 1/200 criteria shall also apply to fixed roof columns.

5.5.4a Weld "peaking" - shall not exceed 1/2".

5.5.4b Weld "banding" - shall not exceed 1/2".

5.5.5 Foundations (General)

5.5.5.2a For concrete ring walls - Top shall be level within  $\pm 1/8$ " in any 30 foot circumference. and within  $\pm 1/4$ " in the total circumference (measured from average elevation).

NOTE: Non-concrete ring walls the values change to  $\pm 1/8$ " in any 10 feet and  $\pm 1/2$ " in total circumference.

5.5.5.3 Sloped foundations - Same criteria.

### SECTION 6 - METHODS OF INSPECTING JOINTS

#### 6.1 Radiographic (Number-Location)

##### 6.1.2.2 Requirements for vertical shell welds

- a. Butt-weld joints with the thinner plate 3/8" or less: One spot in the first 10 feet of each type and thickness welded by each welder or operator. Thereafter, one additional spot in each additional 100 feet.

**NOTE:** At least 25% of spots must be at junctions of verticals and roundseam joints - minimum 2 per tank. Additionally, one random spot in **each** bottom ring vertical.

- b. Plates greater than 3/8" and through 1" thickness - same as thinner plate above **plus all** junctions. Additionally, two spots in **all** bottom ring verticals (one as near to bottom as practical, the other random).
- c. Plates thicker than 1" - full radiography of all verticals, plus all junctions.
- d. Butt weld around periphery of insert nozzles and manways complete radiography.

### 6.1.2.3 Requirements for horizontal shell welds

One spot in the first 10 feet (same type) thickness without regard to welder or operator. Thereafter, one spot in each additional 200 feet.

6.1.2.4 Multi-tank erection (at same location) may use aggregate footage values of same type and thickness.

**NOTE:** See Fig. 6-1 Radiographic Layout.

6.1.2.8 Each radiograph must clearly show 6" minimum weld length.

**NOTE:** Each film must show Identifier, plus "t" gauge or penetrometer.

6.1.2.9 Tank bottom annular ring (See 3.5.1), the radial joints shall be radiographed as follows:

- a. Double-butt-weld joints - one spot on 10% of radial joints.
- b. Single weld joints with back-up bar - one spot on 50% of radial joints.

**NOTE:** Preferable spot - at the outer edge, near shell.

### 6.1.3 Technique - Radiography

6.1.3.1 ASME method, Section V NDE, Article 2.

6.1.3.2 Radiographers meet ASNT - SNT - TC - 1A requirements.

**6.1.5** Radiography Standards - Acceptability to be in accordance with Section VIII, Div. 1, Par. UW-51(B), ASME.

**6.1.6** Unacceptable radiographs (under 6.1.5), or the limits of the deficient radiograph are not defined, 2 adjacent shots are required.

**NOTE:** If adjacent spots are still unacceptable, additional spots are examined until weld is acceptable.

**6.1.7** Weld defects shall be repaired by chipping or melting out from one or both sides, and rewelded.

**6.1.7.2** When all welds are repaired, repeat original inspection procedure.

**6.1.8.1** The manufacturer shall prepare an as-built radiograph map showing the location of all radiographs taken along with the film identification marks.

**6.2.1** Magnetic Particle - ASME Section V, Article 7.

### **6.3 Ultrasonic Examination**

**6.3.1** Ultrasonic Method in lieu of radiography see Appendix U.

**6.3.2** UT not in lieu of radiography - ASME Section V, Article 5

**6.3.2.4** Must be ASNT-SNT-TC-1A requirements

**6.3.2.5** Acceptance standards shall be agreed upon by the purchaser and the manufacturer.

### **6.4 Liquid Penetrant Examination**

**6.4.1** ASME Section V, Article 6 must be followed.

**6.4.2** Must have written procedure

**6.4.3** Manufacturer determines qualifications

**6.4.4** Acceptance standards, ASME Section VIII, Appendix 8, paragraphs 8-3, 8-4 and 8-5.

**6.5.1 Visual acceptability based on following:**

- a. No visible crater or surface cracks or arc strikes.
- b. Undercut does not exceed limits given in 5.2.1.4 for vertical and horizontal butt joints.

**NOTE:** 1/64" maximum allowable undercut on attached nozzles, manways, cleanout openings and permanent attachments.

- c. Frequency of surface porosity does not exceed one "cluster" in any 4" of length and the diameter of each cluster does not exceed 3/32" (0.094").

**6.5.2** All welds failing to meet 6.5.1 requirements must be reworked prior to hydro-testing.

## **SECTION 7 - WELDING PROCEDURE/QUALIFICATIONS**

\* No specifics

## **SECTION 8 - MARKING (NAMEPLATE)**

\* No specifics

## **API - 650 (APPENDIX REVIEW)**

**Appendix A - Optional Design Basis For Small Tanks (Do not use Appendix A on the API 653 Exam).**

**A.1.4** The overturning effect of wind load should be considered.

**A.1.5** Consider Tables A-1 through A-4 for sizes, capacities, shell plate thickness, etc.

**A.2.1** Shell plate thickness limited to 1/2".

**A.5.1** Vertical and horizontal joints, bottom, shell-to-bottom, roof and top angle - same provisions as normal size.

**A.5.2** Normal weld spacing restrictions are relaxed.

**A.5.3** Radiograph inspection - slightly relaxed.

## **Appendix B - Foundation Construction**

**B.2.1** Requires soil coring to determine sub-surface conditions.

### **B.2.3 Varying conditions that require special engineering considerations**

- a. Sites on hillsides.
- b. Sites on swampy or filled ground.
- c. Sites underlain by layers of plastic clay.
- d. Sites adjacent to water courses or deep excavations.
- e. Sites immediately adjacent to heavy structures.
- f. Sites exposed to floodwaters.

### **B.2.4 General methods to improve non-acceptable subsoil**

- a. Removal and replacement with suitable, compacted subsoil.
- b. Compacting with short piles - preloading with an overburden of suitably drained earth.
- c. Removing water content then compacting.
- d. Stabilizing by chemical methods or grout injection.
- e. Driving bearing piles/ foundation piers.
- f. Load distribution over a extra large area.

**B.2.5** Fill material must be sound and durable (i.e., at least equivalent to fill used in good highway construction), free from vegetation, organic matter or other corrosive substances.

### **B.3.1 Suggested grade/surface elevation - 1'.**

### **B.3.2 Finished grade (i.e., surface next to bottom)**

- a. Top 3"-4" - Clean sand, gravel, crushed stone (maximum size 1"), or other suitable inert material.
- b. Equipment and material movement will cause damages. Correct before bottom plates are installed.
- c. Oiled/stabilized finished grade.

### **B.3.3 Finished tank grade**

Crowned from outer edge to center - 1" in 10'.

#### **B.4.2.1 Concrete foundation ringwall advantages**

- a. Better distribution of concentrated load.
- b. Provides a level, solid starting plane for erection.
- c. Provides better means to level tank during erection.
- d. Retains subsoil fill and finished top surface.
- e. Minimizes moisture under tank bottom.

Fig. B-1 - Foundation with Concrete Ringwall.

Fig. B-2 - Foundation with Crushed Stone Ringwall.

**NOTE:** Have familiarity with above types.

### **B.4.3 Earth Foundations** (without concrete ringwall)

- a. A 3' shoulder and berm - protected from weathering.
- b. Smooth, level surface for bottom plates.
- c. Adequate drainage.
- e. Surface true to specified plane (tolerances specified in 5.5.6).

## **Appendix C - External Floating Roofs**

### **C.3.1 General**

If a windskirt or top-shell extension is used for the purpose of containing roof seal at its highest point of travel, appropriate alarm devices are required.

### **C.3.2 Joints**

Same as required in 3.1 (i.e., single lap, full fillet, 1" minimum lap, etc.).

**C.3.3.** On the bottom side, where flexure is anticipated adjacent to girders, support legs, **or other** relatively rigid members, full-fillet welds (not less than 2" long on 10" centers) shall be used on any plate laps that occur within 12" of any such member.

**C.3.3.4** Decks (double and diaphragm) designed for drainage, shall have a minimum slope of 3/16" in 12".

**C.3.4.** Pontoon roofs shall have sufficient buoyancy to remain afloat on a specific gravity product of 0.7 and with primary drains **inoperative** for following conditions:

- a. A 10" of rainfall in a 24 hour period with roof intact, except for double deck floating roofs that have emergency drains.
- b. Single-deck (i.e., diaphragm) and any 2 adjacent compartments punctured in single-deck pontoon types and any 2 adjacent compartments punctured in double-deck roofs -  
Both types with no water or live load.

### **C.3.5 Pontoon Openings**

- a. Each compartment provided with liquid tight manway.
- b. Manway covers provided with suitable hold-down fixture.
- c. Compartments vented against internal/external pressure.



### C.3.8 Roof Drains

- a. Primary drains may be hose, jointed or siphon type.
- b. Check valve required (hose and jointed pipe type) on pontoon and pan type roofs.
- c. Hose drain types designed to permit replacement without personnel entering the tank (\* **Not Normal**).
- d. Minimum roof drain size - 3" for a tank 120 in diameter and less; 4" for a tank greater than 120 feet in diameter.

### C.3.9 Vents

Purchaser furnishes fill and withdrawal flow rates. Fabricator sizes accordingly.

#### C.3.10.1 and 3.10.2 Roof support leg requirements

- a. Pipe legs - notched or perforated at bottom.
- b. Adjustable length from roof top side.
- c. Designed to support roof and a uniform live load of at least 25 lbs./sq. ft.
- d. Sleeves, gussets, etc., required at deck entry points.
- e. Load distribution members required on tank bottom.

**NOTE:** If pads used, continuous weld required.

### C.3.11 Manways

Minimum of 1 with 24" access, with gasket and bolted cover.

### C.3.12 Centering/anti-rotation devices required.

### C.3.13 Seals

- a. The space (rim) between outer roof periphery and shell - sealed by flexible device providing a reasonable close fit to shell surfaces.
- b. No **plain** (i.e., bare) carbon steel shoes allowed.

**NOTE:** Must be galvanized or coated See API RP 2003.

- c. Adequate expansion joints (i.e., secondary seal strips) required.
- d. Must be durable to environment and must not contaminate the product.

**NOTE:** Aviation fuel restrictions.

## C.4 Fabrication, Erection, Welding, Inspection And Testing

C.4.2 Deck and other joint seams tested for leaks with vacuum box, penetrating oil, etc.

**C.4.3** Water flotation test required at initial erection. Weld repair can be seal-weld type.

**C.4.5** 50 PSIG hydro test required on drain system.

### **Appendix D - Technical Inquiries**

(No specific comments)

### **Appendix E - Seismic Design of Storage Tanks**

(No specific comments)

### **Appendix F - Design of Tanks for Small Internal Pressures**

**F.1.3** Internal pressures that exceed the weight of the shell, roof and framing but do not exceed 2 1/2 pounds per square inch gauge when the shell is anchored to a counterbalancing weight, such as a concrete ringwall.

### **Appendix G - Structurally Supported Aluminum Dome Roofs**

(No specific comments)

### **Appendix H - Internal Floating Roofs**

#### **H.1 Scope**

Subsection 3.10 of standard. is applicable except as modified in this appendix.

#### **H.2.2 Types**

- a. Metallic pan internal - liquid contact with two peripheral rims.
- b. Metallic open top bulkhead - liquid contact/peripheral rim and open top bulkheads.
- c. Metallic pontoon - liquid contact/closed pontoons.
- d. Metallic double deck.
- e. Metallic on floats - deck above liquid.
- f. Metallic sandwich-panel - liquid contact, surface-coated honeycomb panels.
- g. Hybrid internal floating roofs.

#### **H.3 Materials**

##### **H.3.2 Steel**

##### **H.3.3 Aluminum**

### H.3.4 Stainless Steel

Same general provisions as for open top floating roofs.

#### H.3.5.2/3.5.7 - Seal types

- a. Flexible foam contained in an envelope
- b. Liquid fill (in an envelope)
- c. Wiper type (resilient)
- d. Metallic Shoe
- e. Other mutually agreeable types (fabrication and customer)

## H.4 General Requirements and Design

### H.4.4 Peripheral Seals

#### H.4.5.1 through 4.5.3 - Design Features

- a. Accommodate  $\pm 4$ " local deviation between roof and shell.
- b. Tank shell free of internal projections, burrs, etc.
- c. Envelope seals to be liquid tight. Field joints, minimum 3" lap.
- d. Mechanical shoe types - Galvanized steel (16 ga.) - Stainless Steel (18 ga).

### H.4.5 Roof Penetrations

Columns, ladders and other rigid vertical appurtenances that penetrate the deck shall have a seal permitting a local deviation of  $\pm 5$ ".

**NOTE:** Appurtenances require a vertical plumbness of 3".

### H.4.6 Roof Supports

#### H.4.6.1 through H.4.6.8 - Specific requirements

- a. Both fixed and adjustable supports are acceptable.
- b. Supports/ attachments designed to support a uniform live load of 12.5 lbs./sq. ft., **unless** roof is equipped with drains to prevent liquid accumulation.
- c. Same underside tack-weld required on seams as on conventional floating roofs. (See C.3.3.3.).
- d. Same requirements on notching pipe legs, welding support pads to bottom, etc., as on conventional.

**NOTE:** Pads may be omitted with purchaser approval.

## H.5 Openings and Appurtenances

## H.5.1 Ladder Specifics

## H.5.2 Vents

### H.5.2.2 Circulation Vents

- a. Located on shell or fixed roof (above seal in full tank).
- b. Maximum spacing - 32". No fewer than 4 total.
- c. Sized equal to or greater than 0.2 sq. ft. per ft. of tank diameter. Covered with corrosion resistant screen and weathershield.

H.5.2.2.2 Open vent required at center of fixed roof minimum area of 50 sq. in.

**NOTE:** Pressure-vacuum vents (rather than air openings) required on gas blanketed tanks.

## H.5.3 Overflow Slots

## H.5.4 Antirotation Devices

## H.5.5 Manholes and Inspection Hatches

## H.6 Fabrication, Erection, Welding, Inspection and Testing

### **Appendix I** - Undertank Leak Detection and Subgrade Protection

(No specific comments) Refer to API RP 652 and 651 for more guidelines.

### **Appendix J** - Shop Assembled Storage Tanks

(No specific comments)

### **Appendix K** - Engineering Data

(No specific comments)

### **Appendix L** - Data Sheets

(No specific comments) In the real world use these sheets as a guide only.

### **Appendix M** - Requirements for Tanks Operating at Elevated Temperatures

(No specific comments)

## **Appendix N - Use of New Materials That are Not Identified**

(No specific comments)

## **Appendix O - Recommendations for Under-Bottom Connections**

(No specific comments)

## **Appendix P - Allowable External Loads on Tank Shell Openings**

(No specific comments)

## **Appendix S - Austenitic Stainless Steel Storage Tanks**

**S.1.1** This section covers tank construction of material grades 304, 304L, 316, 316L, 317, and 317L.

**S.1.2** Ambient temperature tanks shall have a design temperature of 100<sup>0</sup>F

## **Appendix T - NDE Requirements Summary**

## **Appendix U - Ultrasonic Examination in Lieu of Radiography**

(This is a new section, no specific comments)

NAME: \_\_\_\_\_

DATE: \_\_\_\_\_

**The first part of the exam is "Open Book."**

**API 650 Tenth Ed. CODE QUIZ**  
(Select The Best Answer)

1. A peripheral seal, on an internal floating roof, shall be designed to accommodate \_\_\_\_\_ of local deviation between the floating roof and the shell.
  - a. the manufacturer's standard
  - b.  $\pm 100$  mm
  - c.  $\pm 1/8$  inch
  - d. the inspector's experience
  
2. Welders shall be qualified in accordance with \_\_\_\_\_.
  - a. API 1104
  - b. ASME Section V
  - c. ASME Section IX
  - d. AWS D1.1
  
3. A new tank will hold a product with the specific gravity of 1.05. The corrosion allowance is .10. The thickness of the first course is 1.25 inches; The hydrostatic test stress is 25,000 PSI. What is the thickness required for the annular plate? **(Note:** Include corrosion allowance).
  - a. 5/16"
  - b. 11/16"
  - c. 3/8"
  - d. 7/16"
  
4. In order to comply with API 650, the finished surface of a weld reinforcement on plate 1/2" thick, horizontal butt joints, may have a reasonably uniform crown not to exceed \_\_\_\_\_, for radiographic examination.
  - a. 1/4"
  - b. 3/16"
  - c. 1/8"
  - d. 1/16"

5. What is the design thickness for the first course of a new tank 60' tall, with a fill height of 58' and a diameter of 80'4"? The material of construction is A516M 485. Specific gravity of .6
- a. .097
  - b. .416
  - c. 28.1
  - d. .281
6. What is the hydrostatic test shell thickness of the tank in question 5?
- a. .416
  - b. .281
  - c. .117
  - d. .500
7. To what thickness should the tank in question 6 be constructed?
- a. .281"
  - b. .416"
  - c. .500"
  - d. 1.00"
8. If the first course of a new tank is 12.5 mm and the design metal temperature is -7°C, what is the material group?
- a. Group I
  - b. Group II
  - c. Group III
  - d. Group IV
9. What is the maximum reinforcement on a vertical butt joint, if the plate is .625 in. thick?
- a. 3/32"
  - b. 1/8"
  - c. 3/16"
  - d. 1/4"

**Please close all materials.  
The remainder of the Quiz  
is “Closed Book.”**



## The second part of the quiz is "Closed Book."

10. According to API 650, which of the following types of connections shall be stress relieved?
- All nozzles
  - All Group I, II, III or IIIA opening connections less than 12 inches
  - All Group IV, IVA, V or VI opening connections requiring reinforcement
  - All connections requiring reinforcement
11. Upon completion, the roof of a tank designed to be gas tight shall be tested by which one of the following methods?
- Magnetic particle testing of all welds
  - Application of internal air pressure not exceeding the weight of the roof plates and applying a solution suitable for the detection of leaks
  - Penetrant testing the weld joints
  - Visual inspection of the weld joints
12. Each welder making welds on a tank shall be certified by the \_\_\_\_\_.
- erection/fabrication manufacturer
  - purchaser
  - Nuclear Regulatory Commission
  - certified inspector
13. Per API 650, external floating roof deck plates having support leg or other rigid penetrations closer than \_\_\_\_ inches to lap weld seams must be full fillet welded not less than 2 inches on 10 inch centers.
- 6
  - 12
  - 14
  - 18
14. Upon completion of welding of the new tank bottom, the welds shall be inspected by which one of the following methods?
- Radiographs
  - Vacuum or air pressure
  - Penetrant testing
  - Hammer testing

15. The maximum reinforcement thickness for vertical butt joints, less than or equal to 1/2" thick is \_\_\_\_\_.
- a. 1/16"
  - b. 1/8"
  - c. 3/32"
  - d. 3/16"
16. Annular bottom plates shall have a radial width that provides at least \_\_\_\_\_ inches between the inside of the shell and any lap-welded joint in the remainder of the bottom.
- a. 10
  - b. 30
  - c. 24
  - d. 18
17. The maximum acceptable undercutting of the base metal for vertical butt joints is \_\_\_\_\_ inch.
- a. 3/32
  - b. 1/8
  - c. 1/64
  - d. 3/64
18. A double-welded butt weld is \_\_\_\_\_.
- a. a joint between two abutting parts lying in approximately the same plane
  - b. a joint between two abutting parts lying in approximately the same plane that is welded from both sides
  - c. a joint between two overlapping members in which the overlapping edges of both members are welded with fillet welds
  - d. a fillet weld whose size is equal to the thickness of the thinner joined member
19. Openings in tank shells larger than required to accommodate an NPS \_\_\_\_\_ inch flanged or threaded nozzle shall be reinforced.
- a. one
  - b. two
  - c. three
  - d. four
20. The acceptability of welds examined by radiography shall be judged by the standards in \_\_\_\_\_.
- a. ASME Section V, Division 7
  - b. ASME Section IX, Paragraph QW-191
  - c. ASME Section VIII, Division 1, Paragraph UW-51(b)
  - d. API 1104

21. When bottom annular plates are required by paragraph 3.5.1 of API 650, the radial joints shall be radiographed. For single welded butt joints using a backup bar, one spot radiograph shall be taken on \_\_\_\_\_ percent of the radial joints.
- a. 10
  - b. 30
  - c. 50
  - d. 100
22. Annular bottom plates must extend a minimum of \_\_\_\_\_ inches outside the tank shell.
- a. 1 1/2
  - b. 2
  - c. 3
  - d. 4
23. The maximum operating temperature for tanks constructed to API 650 (not including appendices) is \_\_\_\_\_.
- a. 500° F
  - b. 500° C
  - c. 200° F
  - d. 200° C
24. Who is responsible for compliance with the API 650 standards?
- a. Manufacturer
  - b. Purchaser
  - c. State Inspector
  - d. API 653 Inspector
25. A new tank is under construction. How many radiographs are required on the first course vertical welds if the shell is 35 mm thick?
- a. One radiograph shall be taken in every vertical joint
  - b. 100% of the vertical joint
  - c. Two radiographs shall be taken in the vertical joint
  - d. No radiographs required
26. All bottom plates shall have a minimum nominal thickness of \_\_\_\_\_ inch, exclusive of any corrosion allowance specified by the purchaser for the bottom plates.
- a. 3/8
  - b. .250
  - c. .516
  - d. .325

27. Repairs of defects shall not be attempted on a tank that is filled with \_\_\_\_\_ or on a tank that has contained \_\_\_\_\_ until the tank has been emptied, cleaned and gas freed in a safe manner.
- a. nitrogen
  - b. oil
  - c. water
  - d. grain
28. Misalignment in completed vertical joints over 5/8" shall not exceed what percentage of the plate thickness?
- a. 25% with a maximum of 1/16"
  - b. 2% with a maximum of 3/64"
  - c. 5% with a maximum of 3/8"
  - d. 10% with a maximum of 1/8"
29. Reinforcing plates of shell penetrations shall be given a(n) \_\_\_\_\_ test, in accordance with API Standard 650.
- a. diesel
  - b. air
  - c. stress
  - d. gas
30. Ultrasonic acceptance standards, in accordance with API 650, shall be \_\_\_\_\_.
- a. ASME Section VIII
  - b. ASME Section V
  - c. ASME Section XI
  - d. Agreed upon by the purchaser and the manufacturer
31. Column-based clip-guides shall be welded to the tank bottom to prevent \_\_\_\_\_.
- a. internal erosion
  - b. structural uplifting
  - c. lateral movement of column bases
  - d. lateral expansion and contraction
32. Who is responsible for specifying whether the dimensions of a tank will be given in SI units or US customary units?
- a. Industrial requirements
  - b. U.S. Government mandates
  - c. The purchaser
  - d. The manufacturer

33. When performing a vacuum test, the gauge should register a partial vacuum of at least \_\_\_\_\_?
- a. 2 lbf/in.<sup>2</sup>
  - b. 3 lbf/in.<sup>2</sup>
  - c. 4 lbf/in.<sup>2</sup>
  - d. 5 lbf/in.<sup>2</sup>
34. When reviewing a radiograph of an intersection, 2 inches of weld length must be shown on each side of the vertical intersection. How much of the vertical weld must be shown?
- a. 2 inches
  - b. 50 mm
  - c. 3 inches
  - d. No API 653 requirement
35. An appendix becomes a requirement only when \_\_\_\_\_.
- a. the purchaser specifies the requirement.
  - b. API mandates the requirement
  - c. the manufacturer approves the requirement
  - d. required by jurisdictional requirements
36. Shell plates are limited to a maximum thickness of \_\_\_\_\_.
- a. 1"
  - b. 1 1/2"
  - c. 1 3/4"
  - d. 2"
37. Which electrodes are in the AWS A5.1 specification?
- a. E-9018
  - b. E-8518
  - c. E-8018
  - d. E-6010
38. What is the minimum size fillet weld that can be installed on a new tank?
- a. 1/8"
  - b. 3/16"
  - c. 1/4"
  - d. 5/16"

39. Roof plates shall have a minimum nominal thickness, in addition to any required corrosion allowance, of \_\_\_\_\_.
- a. 3/16"
  - b. 1/4"
  - c. 7-Gauge
  - d. both a and c
40. The slope of a supported cone roof shall be at least \_\_\_\_\_.
- a. 1 m in 6 m
  - b. 19 mm in 300 mm
  - c. .75 mm in 12 mm
  - d. 7.5 mm in 1.2 mm
41. Misalignment in completed vertical joints for plates greater than 5/8" thick shall not exceed \_\_\_\_\_.
- a. 10%
  - b. 15%
  - c. 20%
  - d. 25%
42. Low hydrogen electrodes shall be used for weld on \_\_\_\_\_.
- a. the floor only
  - b. the roof only
  - c. shell welds greater than 1/2"
  - d. shell welds less than 1/2"
43. Which of the following NDE methods is not acceptable for the inspection of new shell-to-bottom welds.
- a. Magnetic particle
  - b. Liquid Penetrant
  - c. Vacuum Box
  - d. Radiography
44. A tank construction crew is using a vacuum box constructed of clear plastic and a sponge-rubber gasket.
- a. This is an acceptable practice.
  - b. This is a good vacuum test.
  - c. This vacuum box is not recognized by API 650.
  - d. The crew can use any style vacuum box.

45. Floor plates may be tested by vacuum box testing or \_\_\_\_\_.
- air pressure test
  - tracer gas and compatible detector
  - explosion-bulge test
  - acoustic emission test
46. What is the maximum out-of-plumbness of the top of the shell relative to the bottom of the shell of a new tank that is 65' tall?
- 6.5"
  - 5.4"
  - 3.9"
  - 2.0"
47. Banding at horizontal weld joints shall not exceed \_\_\_\_\_.
- 1/4"
  - 1/2"
  - 3/4"
  - 1"
48. Welds examined by radiography shall be judged as acceptable or unacceptable by \_\_\_\_\_.
- the contractor
  - API 1104
  - ASME Section IX
  - ASME Section VIII
49. A joint between two members that intersect at an angle between 0° (a butt joint) and 90° (a corner joint) is called a(n) \_\_\_\_\_.
- fillet joint
  - butt joint
  - angle joint
  - joint that requires backing
50. The client has requested the top course of a tank to be 1/2" thick. The maximum thickness of all the other courses is 3/8" thick.
- The client wants it, do it.
  - The top course is usually 1/2" thick.
  - No shell course shall be thinner than the course above it.
  - The thickness of each course is based on the design thickness of the tank not including corrosion allowance.

## API 650 Tenth Ed. CODE QUIZ

### Answer Key

1. b (Page H-4, Par. H.4.4.3) API 650
2. c (Page 7-2, Par. 7.3.2) API 650
3. c (Page 3-6, Par. 3.5.3) API 650
4. d (Page 6-3, Par. 6.1.3.4) API 650
5. d (Page 3-7, Par. 3.6.3.2) API 650

Solution:

$$t_d = \frac{2.6D(H-1)G}{S_d} + CA$$

$$t_d = \frac{2.6(80)(58-1)(.6)}{25,300}$$

$$t_d = \frac{7113.6}{25,300}$$

6. a (Page 3-7, Par. 3.6.3.2) API 650

Solution:

$$t_d = .281$$

$$t_t = \frac{2.6D(H-1)}{S_t}$$

$$t_t = \frac{2.6(80)58 - 1}{28,500}$$

$$t_t = \frac{11,856}{28,500}$$

7. b (Page 3-6, Par. 3.6.1.1) API 650
8. a (Page 2-2, Fig. 2-1) API 650
9. b (Page 5-1, Par. 5.2.1.5) API 650
10. c (Page 3-17, Par. 3.7.4.3) API 650
11. b (Page 5-4, Par. 5.3.6.1) API 650
12. a (Page 7-2, Par. 7.3.1) API 650
13. b (Page C-1, Par. C.3.3.3) API 650
14. b (Page 5-4, Par. 5.3.3) API 650
15. c (Page 5-1, Par. 5.2.1.5) API 650
16. c (Page 3-5, Par. 3.5.2) API 650
17. c (Page 5-1, Par. 5.2.1.4) API 650



18. b (Page 3-1, Par. 3.1.1.1) API 650
19. b (Page 3-11, Par. 3.7.2.1) API 650
20. c (Page 6-3, Par. 6.1.5) API 650
21. c (Page 6-3, Par. 6.1.2.9b) API 650
22. b (Page 3-5, Par. 3.5.2) API 650
23. c (Page 1-1, Par. 1.1.1) API 650
24. a (Page 1-2, Par. 1.3) API 650
25. b (Page 6-1, Par. 6.1.2.2c) API 650
26. b (Page 3-5, Par. 3.4.1) API 650
27. b (Page 5-4, Par. 5.4.4) API 650
28. d (Page 5-2, Par. 5.2.3.1) API 650
29. b (Page 5-4, Par. 5.3.4) API 650
30. d (Page 6-4, Par. 6.3.4) API 650
31. c (Page 3-48, Par. 3.10.4.6) API 650
32. c (Page 1-1, Par. 1.1.3) API 650
33. b (Page 6-5, Par. 6.6.3) API 650
34. c (Page 6-1, Par. 6.1.2.2b) API 650
35. a (Page 1-1, Par. 1.1.4) API 650
36. c (Page 2-1, Par. 2.2.1.4) API 650
37. d (Page 2-10, Par. 2.8.1) API 650
38. b (Page 3-1, Par. 3.1.3.3) API 650
39. d (Page 3-44, Par. 3.10.2.2) API 650
40. b (Page 3-48, Par. 3.10.4.1) API 650
41. a (Page 5-2, Par. 5.2.3.1) API 650
42. c (Page 5-2, Par. 5.2.1.10) API 650
43. d (Page 5-2, Par. 5.2.4.1) API 650
44. a (Page 6-4, Par. 6.6.1) API 650
45. b (Page 5-3, Par. 5.3.3) API 650
46. c (Page 5-5, Par. 5.5.2) API 650
47. b (Page 5-5, Par. 5.5.4(b) API 650
48. d (Page 6-3, Par. 6.1.5) API 650
49. c (Page 7-1, Par. 7.1.1) API 650
50. c (Page 3-6, Par. 3.6.1.5) API 650



## **Section 3**

### **API RP 575 – Inspection of Atmospheric & Low-Pressure Storage Tanks**

# API RECOMMENDED PRACTICE 575

## INSPECTION OF

### ATMOSPHERIC AND LOW-PRESSURE STORAGE TANKS

First Edition, November, 1995

#### SECTION 1 - SCOPE

Atmospheric and low-pressure storage tanks that have been in service.

#### SECTION 3 - SELECTED NONDESTRUCTIVE EXAMINATION (NDE) METHODS

##### 3.1 Ultrasonic Thickness Measurement

This section is a discussion of thickness measurements and Dual-element versus single-crystal transducers. The doubling phenomena is mentioned.

##### 3.4 Magnetic Floor Testing

RP 575 now recognizes magnetic floor scanning. MFLT (Magnetic Flux Leakage Testing) is one of the more common types of floor tests. It can be used on bare floor or on some coatings. The principal is basically flooding the area with a magnetic field and measuring any changes in the field. This display will appear on a CRT (Cathode Ray Tube). One of the main limitations of this type of testing is the problem of distinguishing between surface roughness and a through floor pin hole. The process will not evaluate the welds or weld areas. Even with those problems, this is one of the fastest, best methods for inspecting the bottom side or soil side of most tanks.

#### SECTION 4 - TYPES OF STORAGE TANKS

##### 4.1 General

Storage tanks are used in a wide variety of industries for a wide range of products. Basically, our discussion will deal primarily with those that store crude oil, intermediate and finished products, chemicals, water and a general assortment of other products.

For our purposes, the inspection, evaluation and comments dealing with future service conditions and limitations can all be generally categorized together, since conditions that would change the serviceability or repair needs for a tank are basically identical, regardless of the product stored. Other than diameter and height, the only other two (2) service factors to be considered are the specific gravity and temperature of the product.

**4.1.1** Linings as covered in API RP 652 and cathodic protection API RP 651.

## 4.2 Atmospheric Storage Tanks

Those that have been designed to operate in their gas and vapor spaces at internal pressures which approximate atmospheric pressure.

### 4.2.2 Use of Tanks

Atmospheric storage tanks are used to store materials having a true vapor pressure (at storage temperature) which is substantially less than atmospheric pressure.

**NOTE:** Vapor Pressure is the pressure on the surface of the liquid caused by the vapors of the liquid. Vapor pressure varies with temperature, inasmuch as that more of the liquid vaporizes as the temperature rises.

## 4.3 Low-Pressure Storage Tanks

### 4.3.1 Description and Design of Low-Pressure Storage Tanks

Low-pressure storage tanks are those designed to operate at pressures in their gas or vapor spaces exceeding the 2.5 pounds per square inch gauge pressure permissible in API Standard 540, but not exceeding 15 pounds per square inch gauge. Low-pressure tanks are usually built to API Standard 620.

## SECTION 5 - REASONS FOR INSPECTION AND CAUSES OF DETERIORATION

### 5.1 Reasons for Inspection

- a. Reduce the potential for failure and the release of stored products.
- b. Maintain safe operating conditions.
- c. Make repairs or determine when repair or replacement of a tank may be necessary.
- d. Determine whether any deterioration has occurred and, if so, prevent or retard further deterioration.
- e. Keep ground water, nearby waterways and the air free of hydrocarbon and chemical pollution.

#### 5.2.1 External Corrosion

- a. External (underside) tank bottom corrosion results from contamination in the pad. Cinders contain sulfur compounds that become very corrosive when moistened.

- b. Electrolytic corrosion (pitting type) results when clay, rocks, oyster shell, wooden grade stakes, etc., come in contact with the underside bottom, as they attract and hold moisture.
- c. Poor drainage from faulty pad preparation.
- d. Lower external shell corrosion due to:
  - i. Settlement, with corrosion at soil grade line
  - ii. Casual water collection point
  - iii. Insulation moisture "wicking".
- e. Shell appurtenances are subject to crevice corrosion at non-seal welded joints (angles/flats).

### 5.2.2 Internal Corrosion

- a. Primarily dependent on product stored.
- b. Corrosion resistant linings are most common preventative.
- c. Normal locations and causes are:
  - i. Vapor space (above the liquid). Most commonly caused by H<sub>2</sub>S vapor, water vapor, oxygen or a combination of the three.
  - ii. Liquid area. Most commonly caused by acid salts, H<sub>2</sub>S or other sulfur compounds.
- d. Other forms of internal attack, considered as forms of corrosion are:
  - i. Electrolytic corrosion.
  - ii. Hydrogen blistering.
  - iii. Caustic Embrittlement.
  - iv. Graphitic corrosion (cast iron parts).
  - v. Dezincification (brass parts).

In the areas covered by the stored liquid, corrosion is commonly caused by acid salts, hydrogen sulfide or bottom sediment and water (BS&W).

### 5.3 Deterioration of Non-Steel Tanks

- a. Both wooden and concrete tanks may require inspection.
- b. Potential problem areas:
  - i. Wood - subject to rotting, attack by termites, subject to shrinkage, corrosion of the steel bands.
  - ii. Concrete - internal corrosion, cracking due to settlement or temperature change, spalling (exposes reinforcement and corrodes due to atmosphere).

- c. Tanks constructed of other materials (i.e., alloy or aluminum) can present special problems, but are subject to the same mechanical damage potential as steel tanks.
- d. Other nonmetallic tanks (i.e., plastic, fiberglass or glass reinforced epoxy) may present special problems, but will not be discussed in this presentation.

#### 5.4 Leaks, Cracks and Mechanical Deterioration

- a. Leaks, whatever the cause, can cause serious economic losses or environmental damage resulting in fines or penalties by governmental agencies. These, however, pale in comparison to the problems associated with the instantaneous (catastrophic) failure of a shell with resulting loss of the entire tank, the product stored, plus perhaps all surrounding structures.
- b. Plate cracking is always of prime importance when inspecting tanks. Cracks can result from a wide variety of causes. The more frequent causes are:
  - i. Faulty welding.
  - ii. Unrelieved stress concentrations (i.e., stress raisers) around fittings or appurtenances.
  - iii. Stress caused by settlement or earth movement, especially differential settlement
  - iv. Vibration
  - v. Poorly designed repair or "sloppy" craftsmanship.

The most likely points of occurrence are:

- i. Shell to bottom junction.
- ii. Around nozzle and manway connections.
- iii. .Around rivet holes.
- iv. At welded brackets.
- v. At welded seams.

**NOTE:** The lower shell to bottom sketch plate is especially critical in relatively larger or hot tanks. It can act as a plastic hinge with the potential for cracking. See API 650 (Appendix "M").

- c. Many other kinds of mechanical deterioration can develop. In earthquake areas, sloshing damage may occur to roofs. Shell buckling (directly above bottom) can occur in tanks having relatively large height to diameter ratios.
- d. Another form of mechanical deterioration is settlement. Frequent causes are:
  - i. Freezing/thawing of the ground.
  - ii. Unusually high tides in tidal areas.
  - iii. Slow lateral flowing of the soil.

## 5.5 Failure of Auxiliary Equipment

- a. Frequent problem areas are associated with pressure/vacuum conservation vents.
- b. Most common problems are:
  - i. Collection of "gummy" residue on pallets.
  - ii. Moving parts, guide and seat corrosion.
  - iii. Foreign deposits (by birds or insects).
  - iv. Ice formation.
  - v. Tampering.
  - vi. Adding extra weights to pallets (which changes release point of vapor).
  - vii. Lay-down of sand from abrasive blasting.

**NOTE:** Quite often, vents are the only safety relief device available to prevent pressure or vacuum damage.

- c. Other potential auxiliary problem areas:
  - i. Malfunction of gauging system.
  - ii. Floating roof drains.
  - iii. Plugged drain sumps (debris or ice).

## SECTION 6 - FREQUENCY OF INSPECTION

API Standard 653 provides requirements for inspection frequency, including factors to consider in determining inspection frequency.

## SECTION 7 - METHODS OF INSPECTION AND INSPECTION SCHEDULING

The first part of this section deals with safety aspects of entry. The next section is a current list of tools commonly used in tank inspection and a suggested list of equipment that might be needed in tank inspection.

### 7.2 External Inspection of In-Service Tank

See Appendix C, Table C-1 and C-2 of this RP.

#### 7.2.3 Foundation Inspection

Refer to API Standard 653 for limitation.

#### 7.2.4 Anchor Bolt Inspection

The condition of anchor bolts can usually be determined by visual inspection. The hammer and UT thickness methods are also described in this section.

## 7.2.6 Grounding Connection Inspection

The total resistance from tank to earth should not exceed approximately 25 ohms.

## 7.2.8 Insulation Inspection

Under insulation corrosion is now considered to be a more severe problem than previously thought.

- a. A visual examination is usually, but not always, sufficient to spot problem areas.
- b. Areas to be more closely checked include:
  - i. Around all nozzles and appurtenances, especially if the caulking bond is loose or points for casual water entry is evident.
  - ii. Around saddles where movement or expansion may have damaged insulation or seal.
  - iii. Around open-bubbles on polyurethane foam systems.
  - iv. Along bottom edge where moisture "wicking" may have occurred.
  - v. Along roof to shell junction, unless this area is protected by an overhand "rat-guard" type insulation support brackets (where block insulation is used).

### 7.2.9.1 Thickness Measurements

Ultrasonic-thickness measurements should be conducted only by trained personnel using a properly calibrated thickness measurement instrument and an appropriate thickness measurement procedure.

### 7.2.9.3 Caustic Cracking

If caustic or amine is stored in a tank, the tank should be checked for evidence of damage from caustic stress corrosion cracking, sometimes referred to as caustic embrittlement.

## 7.4.4 Tank Bottoms

This section suggests inspection of the entire tank bottom by using Magnetic Flux Leakage, looking for bottom side corrosion. Other UT type techniques may also be used. A-scan or shear wave ultrasonic testing may be used under specific conditions. Hammer-testing is also mentioned as a testing technique.



#### 7.4.6 Testing for Leaks

The usual types of tests are mentioned, hydrostatic tests, vacuum box tests, external water bottom tests and tracer gas tests. Another method being used successfully is the injection of inert gas with a tracer gas under the tank. Instruments capable of detecting a few parts per million (PPM) of the tracer gas are then used for “sniffing” for leaks on the topside of the tank floor. An advantage of such a method is that welded repairs can be made immediately with the inert gas under the bottom and a re-check can be made immediately after repairs.

#### 7.5 Testing of Tanks

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

#### 7.6 Inspection Scheduling

The two main aspects to consider when inspecting a tank:

- a. the rate at which deterioration is proceeding; and
- b. the safe limit of deterioration.

The following may be used for most common forms of deterioration, metal corrosion, the rate of metal loss and the remaining life of a tank component.

$$\text{Remaining life} = \frac{t \text{ actual} - t \text{ minimum}}{\text{corrosion rate}}$$

Where:

Remaining life = the remaining life of a tank component, in years

$t$  actual = the thickness measured at the time of the inspection for a given location or component used to determine the minimum allowable thickness, in inches.

$t$  minimum = the minimum allowable thickness for a given location or component, in inches.

$$\text{Corrosion rate} = \frac{t \text{ previous} - t \text{ actual}}{\text{in years between } t \text{ actual and } t \text{ previous}}$$

$t$  previous =- thickness at the same location as  $t$  actual measured during a previous inspection, in inches.

## **7.7 Inspection Checklists**

Inspection checklists should be used judiciously by the inspector as “memory joggers” for issues and items to be checked during inspection, both internal and external.



## **Section 4**

### **API RP 651 – Cathodic Protection Aboveground Petroleum Storage Tanks**

API-RP-651  
CATHODIC PROTECTION OF ABOVEGROUND  
PETROLEUM STORAGE TANKS

SECOND EDITION, DECEMBER 1997

SECTION 1 - GENERAL

**1.1 Scope**

Recommended practices covered by this presentation is to present procedures, practices, information and guidance for achieving effective corrosion control on above ground hydrocarbon storage tank bottoms. It contains provisions for the application of cathodic protection to existing and new storage tanks.

Corrosion control methods based on chemical control of the environment and the use of protective coatings are not covered in detail. Certain recommended practices may also be applicable to tanks in other than hydrocarbon service. This is intended to serve only as a guide. Specific cathodic protection design is not provided. Every tank condition is not covered. Standardization is precluded because of the varied conditions for field application.

**2.0 Referenced Publications**

**3.0 Definitions**

Definitions in this section reflect the common usage among practicing corrosion control personnel. In many cases, in the interests of brevity and practicality, the strict scientific definitions have been abbreviated or paraphrased.

- 3.1 aboveground storage tank:** A stationary container of greater than 500 barrel capacity, usually cylindrical in shape, consisting of a metallic roof, shell, bottom, and support structure where more than 90 percent of the tank volume is above surface grade.
- 3.2 anode:** An electrode of an electrochemical cell at which oxidation (corrosion) occurs. Antonym: cathode.
- 3.3 backfill:** Material placed in a hole to fill the space around anodes, vent pipe, and buried components of a cathodic protection system. Anodes can be prepackaged with backfill material for ease of installation.
- 3.4 breakout piping:** All piping associated with the transfer of products in and out of storage tanks.
- 3.5 cathode:** An electrode of an electrochemical cell at which a reduction reaction occurs. Antonym: anode.
- 3.6 cathodic protection:** A technique for preventing corrosion by making the

entire surface of the metal to be protected act as the cathode of an electrochemical cell.

- 3.7 **coke breeze:** A carbonaceous backfill material.
- 3.8 **continuity bond:** A metallic connection that provides electrical continuity.
- 3.9 **corrosion:** The deterioration of a material, usually a metal, that results from a reaction with its environment.
- 3.10 **current density:** The current per unit area flowing to or from a metallic surface.
- 3.11 **current requirement test:** Creates direct current flow from a temporary ground bed to the structure to be protected to determine the amount of current necessary to protect that structure.
- 3.12 **deep anode groundbed:** One or more anodes installed vertically at a nominal depth of 15m (50 ft) or more below the earth's surface in a single drilled hole for the purpose of supplying cathodic protection.
- 3.13 **differential aeration cell:** An electrochemical cell the electromotive force of which is due to a difference in air (oxygen) concentration at one electrode as compared with that at another electrode of the same material.
- 3.14 **electrical isolation:** The condition of being electrically separated from other metallic structures and the environment.
- 3.15 **electrical isolation cell:** An electrical circuit where electrical current flows from certain areas of a metal to other areas through a solution capable of conducting electricity (electrolyte).
- 3.16 **electrochemical cell:** An electrochemical system consisting of an anode and a cathode immersed in an electrolyte so as to create an electrical circuit. The anode and cathode may be separate metals or dissimilar areas on the same metal. The cell includes the external circuit which permits the flow of electrons from the anode toward the cathode.
- 3.17 **electrode potential:** The potential of an electrode as measured against a reference electrode. (The electrode potential does not include any resistance losses in potential in either the electrolyte or the external circuit. It represents the reversible work required to move a unit charge from the electrode surface through the electrolyte to the reference electrode).
- 3.18 **electrolyte:** A chemical substance containing ions that migrate in an electric field. For the purposes of this recommended practice, electrolyte refers to the soil or liquid adjacent to and in contact with the bottom of an aboveground petroleum storage tank, including the moisture and other chemicals contained therein.
- 3.19 **environmental cracking:** The brittle fracture of a normally ductile

material in which the corrosive effect of the environment is a causative factor.

- 3.20 **external circuit:** Consist of the wires, connectors, measuring devices, current sources, etc., that are used to bring about or measure the desired electrical conditions within an electrochemical cell. It is this portion of the cell through which electrons travel.
- 3.21 **foreign structure:** Any metallic structure that is not an intended part of the system in question.
- 3.22 **galvanic anode:** A metal that, because of its relative position in the galvanic series, provides sacrificial protection to another metal that is more noble, when coupled in an electrolyte. These anodes are the source of current in one type of cathodic protection.
- 3.23 **galvanic series:** A list of metals and alloys arranged according to their relative potentials in a given environment.
- 3.24 **groundbed:** Consists of one or more anodes installed below the earth's surface for the purpose of supplying cathodic protection.
- 3.25 **holiday:** A discontinuity in a protective coating that exposes unprotected surface to the environment.
- 3.26 **impressed current:** An electric current supplied by a device employing a power source that is external to the electrode system. (An example is direct current for cathodic protection).
- 3.27 **insulating coating system:** All components of the protective coating, the sum of which provides effective electrical insulation of the coated structure.
- 3.28 **interference bond:** A metallic connection designed to control electrical current interchange between metallic systems.
- 3.29 **IR drop:** The voltage generated across a resistance by an electrical current in accordance with Ohm's Law:  $E=I \times R$ . For the purpose of this recommended practice, IR drop is the portion of a structure-to-soil potential caused by a high resistance electrolyte between the structure and the reference electrode or by current flow from the anodes to the tank bottom.
- 3.30 **isolation:** Electrical isolation.
- 3.31 **liner:** A system or device, such as a membrane, installed beneath a storage tank in or on the tank dike, to contain any accidentally escaped product.
- 3.32 **membrane:** A thin, continuous sheet of non conductive synthetic material

used to contain and/or separate two different environments.

- 3.33 **oxidation:** The loss of electrons by a constituent of chemical reaction.
- 3.34 **polarization:** The change from the open circuit potential of an electrode resulting from the passage of current. (In this recommended practice, it is considered to be the change of potential of a metal surface resulting from the passage of current directly to or from an electrode).
- 3.35 **rectifier:** A device for converting alternating current to direct current. Usually includes a step-down AC transformer, a silicon or selenium stack (rectifying elements) , meters and other accessories when used for cathodic protection purposes.
- 3.36 **reduction:** The gain of electrons by a constituent of a chemical reaction.
- 3.37 **reference electrode:** A device whose open circuit potential is constant under similar conditions of measurement.
- 3.38 **resistor:** A device used within an electrical circuit to control current flow.
- 3.39 **sacrificial anode:** Another name commonly used for a galvanic anode.
- 3.40 **sacrificial protection:** The reduction or prevention of corrosion of a metal in an electrolyte by galvanically coupling it to a more anodic metal.
- 3.41 **secondary containment:** A device or system used to control the accidental escape of a stored product so it may be properly recovered or removed from the environment. For the purposes of the recommended practice, secondary containment refers to an impermeable membrane.
- 3.42 **shallow anode groundbed:** A group of cathodic protection anodes installed individually, spaced uniformly, and typically buried less than 20 feet below grade.
- 3.43 **shunt:** A conductor of a known electrical resistance through which current flow may be determined by measurement of the voltage across the conductor.
- 3.44 **stationary:** Something that is permanently installed on the ground or on a foundation.
- 3.45 **stray current:** Current flowing through paths other than the intended circuit.
- 3.46 **stray current corrosion:** Corrosion resulting from direct current flow through paths other than the intended circuit.
- 3.47 **stress corrosion cracking:** The fracture of a metal by the combined action

of corrosion and tensile stress that may be well below the tensile strength or even the yield strength of the material.

- 3.48 **structure-to-electrolyte voltage** (also structure-to-soil potential or pipe-to-soil potential): The voltage difference between a metallic structure and the electrolyte which is measured with a reference electrode in contact with the electrolyte.
- 3.49 **structure-to-structure voltage** (also structure-to-structure potential): The difference in voltage between a metallic structures in a common electrolyte.
- 3.50 **tank cushion:** The material immediately adjacent to the exterior steel bottom of an aboveground storage tank.
- 3.51 **tank pad:** Another name for a tank cushion.
- 3.52 **test lead:** An electrically conductive cable attached to a structure and leading to a convenient location. It is used for the measurement of structure-to-electrolyte potentials and other measurements.
- 3.53 **test station:** A small enclosed box-like housing and the usual termination point of one or more test leads.
- 3.54 **voltage:** Refers to an electromotive force, or a difference in electrode potentials expressed in volts. Also known as a potential.
- 3.55 **water bottom:** A water layer in the bottom of a tank caused by separation of water and product due to differences in solubility and specific gravity.

## SECTION 4- CORROSION OF ABOVEGROUND



## STEEL STORAGE TANKS

**4.1.1** Corrosion may be defined as the deterioration of a metal due to a reaction to its environment. Corrosion of steel structures is an electrochemical process. The corrosion process occurs when:

- a. Areas with different electrical potentials exist on the metal surface.
- b. These areas must be electrically connected.
- c. Areas must be in contact with an electrolyte. Moist soil is the most common electrolyte for external surfaces of the tank bottom. Water and sludge are, generally, the electrolytes for internal surfaces.

**NOTE:** There are four (4) components in each corrosion cell:

1. An anode
2. A Cathode
3. A metallic path connecting the anode and cathode. (See Fig. 1)
4. An electrolyte

**4.1.2** Many forms of corrosion exist. The two (2) most common (relative to tank bottoms) are general and pitting corrosion.

- a. General type: Thousands of microscopic corrosion cells occur on an area of the metal surface resulting in relatively uniform metal loss.
- b. Pitting type: Individual cells are larger and distinct anode and cathode areas can be identified.

**NOTE:** Corrosion occurs at the **Anode**. Metal loss may be concentrated within relatively small areas with substantial surface areas unaffected.

### 4.1.3 through 4.1.5

Conditions that influence which areas of a surface become anodic or cathodic and/or corrosion cells are:

- a. Composition of the metal.
- b. Differences in electrochemical potential (i.e., uneven distribution of alloying elements or contaminants within the metal structure).
- c. Differences between the weld bead, the heat affected zone and the parent metal.
- d. Physical and chemical properties of the electrolyte.
- e. Differences in oxygen concentrations.
- f. Soil characteristics (i.e., dissolved salts, moisture content, pH, etc.).
- g. Clay, wood or other debris in bottom contact.

## 4.2 Corrosion Mechanisms

- 4.2.1 Stray current corrosion occurs when stray currents (also known as interference currents) travel through the soil electrolyte and on to structures for which they **are not** intended.

**NOTE:** The most common, and potentially more damaging, stray currents are direct currents (i.e., grounded DC electric power systems) such as electric railroads, subways, welding machines, impressed current cathodic protection systems and thermoelectric generators.

The severity of corrosion resulting from interference currents depend on the following:

- a. Separation and routing of the interfering and affected structures and the location of the interfering current source.
- b. Magnitude and density of the current.
- c. Quality of or absence of a coating on the affected structure.
- d. Presence and location of mechanical joints having high electrical resistance.

- 4.2.2 Bimetallic Corrosion occurs when two (2) metals with different compositions (thus different electrolytic potentials) are connected in an electrolyte (usually soil). (See Fig. 4).

**NOTE:** Current flows from the more active metal (anode) to the less active metal (cathode) with resulting accelerated attack at the anode. **Examples:** Bronze check valve to steel piping. Stainless Steel or Copper pipe to steel tank.

- 4.2.3 Internal Corrosion may occur on the inside surface of a tank bottom. Factors influencing severity are:

- a. Conductivity (2 function of dissolved solids).
- b. Suspended solids
- c. pH level
- d. Dissolved gases such as CO<sub>2</sub>, H<sub>2</sub>S or O<sub>2</sub>.

## SECTION 5 - DETERMINATION OF NEED FOR CATHODIC PROTECTION

#### 5.1.4 Limitations

Cathodic protection is an effective means of corrosion control **only** if it is possible to pass electrical current between the anode and cathode (i.e., tank bottom). Many factors can either reduce or eliminate the flow of electrical current, reducing protection effectiveness. Such factors include:

- a. Foundations such as concrete, asphalt or oiled sand.
- b. An impervious lining between the tank bottom and anodes such as in secondary containment systems.
- c. High resistance soil or rock foundations.
- d. Old storage tank bottoms left in place when a new bottom is installed.

## SECTION 6 - METHODS OF CATHODIC PROTECTION FOR CORROSION CONTROL

### 6.1 Introduction

Cathodic protection is a technique for preventing corrosion by making the entire surface of the metal act as the cathode of an electrochemical cell. The two (2) methods of protection are:

- a. Sacrificial anode
- b. Impressed current.

### 6.2 Galvanic Systems

**6.2.1** Use of a metal more active than the structure to be protected to supply the current required to stop corrosion. See Table 3 (Page 10 code) for a partial galvanic series. The more active metal is called a sacrificial anode.

**Example:** The anode is electrically connected to the structure and buried in the soil. A galvanic corrosion cell develops and the active metal anode corrodes (is sacrificed) while the metal structure (cathode) is protected.

**NOTE:** Metals commonly used as sacrificial anodes in soil are magnesium and zinc (in either cast or ribbon form). Usually distributed around the perimeter of the tank or buried beneath the bottom.

**6.2.2** Advantages of Galvanic Systems

- a. No external power supply is required.
- b. Installation is easy.
- c. Capital investment is low.
- d. Minimum maintenance costs.
- e. Interference problems (stray currents) are rare.
- f. Less frequent monitoring required.

**6.2.3** Disadvantages of Galvanic Systems

- a. Driving potential is limited.
- b. Current output is low.
- c. Method is limited to use in low-resistivity soils.
- d. Not practical for protection of **large** bare structures.

### 6.3 Impressed Current Systems

6.3.1 Uses DC usually provided by a rectifier (i.e., device for changing AC into DC). DC flows from the rectified to the buried impressed current anode.

#### 6.3.2 Advantages of Impressed Current Systems

- a. Availability of large driving potential.
- b. High current output for protecting large structures.
- c. Capability of variable current output.
- d. Applicable to almost any soil resistivity.

#### 6.3.3 Disadvantages of Impressed Current Systems

- a. Interference problems (i.e., stray currents) on foreign structures.
- b. Loss of AC power causes loss of protection.
- c. Higher costs (maintenance and operating).
- d. Higher capital costs.
- e. Safety aspects of rectifier location.
- f. Safety aspects of negative lead connections.
- g. More frequent monitoring.

#### 6.3.4 Rectifiers - Two (2) major components:

- a. Step-down transformer (reduces AC supply voltage).
- b. Rectifying elements to provide DC output.

**NOTE:** Silicon rectifiers are more efficient, but are troubled by power surges, (i.e., lightning prevention devices required). Selenium rectifiers are used, but have decreased life span if ambient temperature exceeds 130°F.

6.3.5 Impressed Current Anode materials are graphite, steel, high silicon cast iron or mixed metal oxides on titanium. Usually buried in a coke breeze backfill (reduces circuit resistance), in remote groundbeds, distributed around or under the tank or installed in deep groundbeds.

## SECTION 7 - DESIGN OF CATHODIC PROTECTION SYSTEMS

When dealing with your client/customer, be aware of certain conditions that may influence your job assessment/evaluation. These items include:

- 7.2.1 Anything that acts as a **barrier** to the flow of current will prevent the application of cathodic protection.
- 7.2.2 Tank bottom replacement has a significant impact on protection effectiveness. If cathodic systems exist, or installation is planned for the new bottom, **the old bottom must be removed.**

**NOTE:** If the old bottom remains in place, even with cathodic systems installed **between** the old and new bottoms, future problems may occur. If a conductive electrolyte exists between the bottoms, the current flow and metal loss will be from the new bottom.

7.2.5.1 Secondary containment systems between bottoms (i.e., impermeable membranes) have both good and bad features relative to cathodic protection.

7.2.5.1.1 Advantages

- a. Contains leaks and prevents ground contamination.
- b. Eliminates current flow between bottoms.
- c. Prevents ground water wicking into sand pad.

7.2.5.1.2 Disadvantages

- a. Future addition of cathodic protection impossible.
- b. Membrane acts as a basin to contain electrolyte.
- c. With leak, traps hydrocarbon, becomes "hot-work" issue.

**SECTION 8 - CRITERIA FOR CATHODIC PROTECTION:**

When has adequate protection been achieved and does it still exist?

## 8.2 Protection Criteria

Developed from lab experiments or from existing, successful systems.  
Minimum requirements are listed below.

8.2.2.1 A negative (cathodic) potential of at least 850 mV with the cathodic protection current applied.

8.2.2.2 A negative polarized potential of at least 850 mV relative to a CSE.

8.2.2.3 A minimum of 100 mV of cathodic polarization measured between the tank bottom metallic surface and a stable reference electrode contacting the electrolyte.

## 8.3 Measurement Techniques

8.3.1 The standard method of determining the effectiveness of cathodic protection on a tank bottom is the tank-to soil potential measurement.

- NOTE:**
1. Measurement is performed using a high-impedance (i.e., resistance) voltmeter and a stable, reproducible reference electrode contacting the electrolyte. (See Fig. 10)
  2. Perimeter measurement may not represent potential at the center of the tank bottom.

## SECTION 9 - INSTALLATION OF CATHODIC PROTECTION SYSTEMS

(No specific notes)

## SECTION 10 - INTERFERENCE CURRENTS

(No specific notes)

## SECTION 11 - OPERATION AND MAINTENANCE OF CATHODIC PROTECTION SYSTEMS

## 11.1 Introduction

Coupled with operation and maintenance, Field inspection surveys (to determine that cathodic protection has been established and that it is currently effective) should be established. A few items that should be considered include:

- a. Conditions that affect protection are subject to change with time.
- b. Changes may be required to maintain (or even establish) protection.
- c. If tanks are empty, large areas of the bottom **may not** be in contact with underlying soil. Potential surveys, may therefore, be misleading.

**NOTE:** Potential surveys should be made with sufficient product gauge so as to maximize bottom-cushion contact.

- d. Initial surveys (on new installation) should not be conducted until after adequate polarization (i.e., a positive or negative condition) has occurred. This is generally 6-18 months after system energized.

**11.3.1** Surveys should include one or more of the following:

- a. Structure-to-soil potential.
- b. Anode current.
- c. Native structure-to-soil potentials.
- d. Structure-to-structure potential.
- e. Piping to tank isolation (if protected separately).
- f. Effect on adjacent structures.
- g. Continuity of structures (if protected as single structure).
- h. Rectifier DC volts, DC amps, efficiency and tap settings.

## 11.4 Cathodic Protection Records

Depending on need, circumstance and customer direction, the following should be considered as permanent record needs:

- a. Design and location of insulating devices.
- b. Results of current requirement tests, where made and procedures used.
- c. What was native structure-to-soil potential **before** current was applied.
- d. Results of soil resistivity (resistance) test at the site, where made and procedures used.
- e. Type of system (i.e., sacrificial anode, impressed current, etc. ).
- f. Repair of rectifiers, other DC power sources required.
- g. Repair/renewal of anodes, connections or cable.



## **Section 5**

### **API RP 652 – Lining of Aboveground Petroleum Storage Tank Bottoms**



LINING OF ABOVEGROUND PETROLEUM STORAGE TANK BOTTOMS

SECOND EDITION, DECEMBER 1997

SECTION 1 - GENERAL

1.1 Scope

This recommended practice describes the procedures and practices for achieving effective corrosion control in aboveground storage tanks by application of tank bottom linings to existing and to new storage tanks.

This recommended practice also provides information and specific guidance for tanks in hydrocarbon service. Some of the practices may also be applicable for other services.

NOTES:

1. This **does not** designate specific bottom linings for all situations because of the wide variety of service environments.
2. This recommended practice is a guide only.
3. Detailed lining specifications are not included.

2.0 Referenced Publications

3.0 Definitions

- 3.1 **aboveground storage tank:** A stationary container, usually cylindrical in shape, consisting of a metallic roof, shell, bottom and support structure where more than 90% of the tank volume is above surface grade.
- 3.2 **adduct:** A curing agent, generally an amine, that has been combined with a portion of the resin, usually an epoxy.
- 3.3 **amine:** An organic compound having amino functional groups which provide chemical reactivity and utility as a curative for epoxy and other resins.
- 3.4 **anchor pattern:** Surface profile or roughness.
- 3.5 **anode:** The electrode of an electrochemical cell at which oxidation (corrosion) occurs. Electrons flow away from the anode in the external circuit. Corrosion usually occurs and metal ions enter the solution at the anode. \* Antonym: cathode.
- 3.6 **aromatics:** Strong hydrocarbon solvents whose chemical structure has an

unsaturated ring with delocalized pi electrons. Benzene, toluene and xylene are common examples of aromatic solvents.

- 3.7 **bisphenol-A polyester:** A polyester whose chemical structure incorporates Bisphenol-A into the resin molecule in place of some or all of the glycol. The solid resin is generally provided a solution in styrene, which acts as a solvent and as a cross-linking agent for the resin.
- 3.8 **cathode:** An electrode of an electrochemical cell as which a reduction is the principle reaction. Electrons flow toward the cathode in the external circuit. \* Antonym: anode
- 3.9 **cathodic protection:** A technique for to reduce corrosion of a metal surface by making that surface the cathode of an electrochemical cell.
- 3.10 **coal tar:** A black hydrocarbon residue remaining after coal is distilled.
- 3.11 **coal tar epoxy:** A coating in which the binder is a combination of coal tar and epoxy resin.
- 3.12 **copolymer:** A large molecule whose chemical structure consists of at least two (2) different monomers.
- 3.13 **corrosion:** The deterioration of a material, usually a metal, because of a reaction with its environment.
- 3.14 **curing:** The setting up, or hardening, generally due to a polymerization reaction between two (2) or more chemicals (resin and curative).
- 3.15 **dew point:** Pertains to the temperature at which moisture condenses from the atmosphere.
- 3.16 **differential aeration cell:** An electrochemical cell , the electromotive force of which is due to a difference in air (oxygen) concentration at one electrode as compared with that at another electrode of the same material.
- 3.17 **electrochemical cell:** A system consisting of an anode and a cathode immersed in an electrolyte so as to create an electrical circuit. The anode and the cathode may be different metals or dissimilar areas on the same metal surface.
- 3.18 **electrolyte:** A chemical substance containing ions that migrate in an electric field.
- 3.19 **epoxy:** Resin containing epoxide (oxirane) functional groups that allow for curing by polymerization with a variety of curatives. Epoxy resins are usually made from Bisphenol-A and epichlorohydrin.
- 3.20 **forced-curing:** Acceleration of curing by increasing the temperature above ambient, accompanied by forced air circulation.
- 3.21 **holiday:** A discontinuity in a coating film that exposes the metal surface

to the environment.

- 3.22 isophthalic polyester:** A resin polymerized from isophthalic acid (or anhydride), ethylene or propylene glycol and malic acid (or anhydride). The solid resin is generally provided as a solution in styrene, which acts as a solvent and as a cross-linking agent for the resin.
- 3.23 lining:** A coating bonded to the internal surfaces of a tank to serve as a barrier to corrosion by the contained fluids.
- 3.24 mil:** One one-thousandth of an inch (0.001").
- 3.25 mill scale:** An oxide layer formed on steel during hot forming operations.
- NOTE:** Appearance: slick, smooth, shiny surface area.
- 3.26 phenolic:** A resin of the phenol-formaldehyde type.
- 3.27 polyamide:** A resin whose chemical structure contains adjacent carbonyl and amino functional groups that is often used as a curative for epoxy resins. Commercially available polyamides are reaction products of dimerized and trimerized fatty acids and polyamines.
- 3.28 polyamidoamine:** A resin whose chemical structure contains adjacent carbonyl and amino functional groups that is often used as a curative for epoxy resins. Commercially available polyamides are reaction products of dimerized and trimerized fatty acids and polyamines.
- 3.29 resin:** A natural or synthetic substance that may be used as a binder in coatings.
- 3.30 vinyl-ester:** A polyester that usually contains Bisphenol-A in the resin backbone and two vinyl groups for reactivity. The solid resin is generally provided as a solution in styrene, which acts as a solvent and as a cross-linking agent for the resin.
- 3.31 vinyl group:** A functional group on a resin molecule that contains a carbon-to-carbon double bond at the end of the molecule.

## SECTION 4 - CORROSION MECHANISMS

## 4.1 General

The common mechanisms of internal storage tank bottom corrosion include:

- a. Chemical corrosion
- b. Concentration cell corrosion
- c. Galvanic cell corrosion
- d. Corrosion caused by sulfate-reducing bacteria
- e. Erosion corrosion.

**NOTES:**

1. Carbon steel corrosion rates in various hydrocarbon services have been established. Refer to NACE 510700.
2. These apply **only** if there are **no** accelerating mechanisms present.

**Example:** Water collection on tank bottoms may contain salt and sediment that "settles out" on bottom plates. The chlorides and other soluble salts may provide a strong electrolyte which can promote corrosion.

## 4.2 Chemical Corrosion

- a. Normally seen in environmental and product clean-up tanks. Concentrated acids, added to water (with heat) to break emulsion of oil and water, becomes deluded. Diluted acid is much more corrosive than stronger acids.
- b. Chemical attack also occurs in caustic, sulfuric acid, ballast water and water neutralization services.

## 4.3 Concentration Cell Corrosion

Occurs in lower oxygen concentration areas (i.e., surface deposit, mill scale or crevice).

**NOTE:** Recognized as pitting or in a significant localized metal loss area.

## 4.4 Galvanic Cell Corrosion

Formation of a bi-metallic corrosion couple due to the presence of an electrolyte (i.e., dissolved oxygen). The common locations for occurrence are:

- a. Breaks in mill scale.
- b. HAZ adjacent to welds

**NOTE:** Also noted by significant localized metal loss.

## 4.5 Corrosion Caused by Sulfate-Reducing Bacteria

- a. Phenomenon recognized but not understood.
- b. Usually negligible, occasionally service.
- c. Thought to be associated with concentrated cell corrosion, due to deposits forming a barrier to the diffusion of dissolved oxygen.

#### 4.6 Erosion Corrosion

Normally occurs in mixing tanks where soil particles or small aggregate are present and movement occurs (i.e., waste water treating or mixing, adjacent to mixers in crude tanks). The movement of aggregate causes abrasive attack. Normally seen as "well defined" loss pattern.

### SECTION 5 - DETERMINATION OF NEED for TANK BOTTOM LININGS

#### 5.1 General

Tank bottoms normally fabricated from carbon steel plate sections typically 1/4" (6 mm) thick. Annular floor plate rings may be thicker (up to 1/2" (12 mm)). Sketch plates (under shell) of 5/16" plate may often be found in older tanks. The need for an internal tank bottom lining is generally based upon one or more of the following:

- a. Corrosion prevention
- b. Tank design
- c. Tank history
- d. Environmental considerations
- e. Flexibility for service change
- f. Upset conditions
- g. Federal, State or local regulations.

#### 5.2 Linings for Corrosion Prevention

Proper selection and application of bottom linings can prevent internal bottom corrosion.

**NOTE:** If the tank bottom measurements indicate that a "t" of 0.100" exists, or will be present **prior** to the next schedule turnaround, then a recommendation for applying a lining should be strongly considered.

#### 5.3 Design Considerations and Tank Internals

Design or fabrication details that would jeopardize the integrity, or limit the life expectancy or effectiveness, may exist.

**Example:** Steam coils limit accessibility for surface preparation. The resulting thermal effects effect may cause localized failure by blistering or cracking.

#### 5.4 Tank History

- a. Consider corrosion history when determining need for lining.
- b. Consider history of other tanks in similar service.
- c. Some important considerations are:
  - i. Where is corrosion problem occurring (product side, soil side, outer periphery, etc.)?
  - ii. How fast is corrosion proceeding?
  - iii. Has there been a significant change in corrosion rate?
  - iv. What type of corrosion is occurring?
  - v. Has through-bottom penetration occurred?

#### 5.4.1 Tank Foundation

Inadequate foundation can cause tank settlement, bottom flexing may occur, causing the internal lining to fail by cracking.

#### 5.4.2 Methods of Construction

- a. Irregular surfaces (i.e., rivets, butt straps and skip welding) are difficult to cover and protect with a lining.
- b. Older tank lining application may be complicated by chemical contaminants.
- c. Column bases and roof leg support pads may present application problems.

5.4.2.1 If a prior liner is present, and a portion is to be salvaged and reused, the new liner application and material must be compatible.

5.4.2.2 Previous Repairs: Prior mechanical repair/additions must be considered. Such as, are there odd-shaped patches to cover, support-angles to seal, no back-welded or hot-taps that will require special crevice sealing solutions?

5.4.2.3 Prior Storage: Special cleaning techniques, or degree of cleaning required must be considered when evaluating which type of coating is most effective.

**NOTE:** Most major material suppliers have data and technical expertise that can be requested. The data should be free, the technical help will add to costs.

### 5.5 Environmental Considerations

Properly applied internal linings reduce the chance of external environmental contamination. Cathodic protection also usually reduces underside bottom loss.

#### 5.5.1 Location

When considering the need for an internal lining, always consider:

- a. The potential for ground water contamination in hydrogeologically sensitive areas.
- b. Proximity to populated areas or public roads.
- c. Proximity to rivers, lakes, parks or scenic areas.
- d. Presence/location of containment dikes.

## 5.6 Flexibility for Service Change

- a. Changes in service may drastically affect the performance of existing liners.
- b. If "swing-service" is expected of the tank involved, then all potential services and their compatibility with internal lining being considered must be carefully and fully evaluated.
- c. **Remember:** Tank linings **do not** offer universal resistance. Product make-up varies. Therefore, properties of the lining must vary. Again, technical assistance from the liner supplier can be of great value.

## 5.7 Upset Conditions

Don't forget the impact involved. Consult customer as to potential for occurrence.

# SECTION 6 - TANK BOTTOM LINING SELECTION

## 6.1 General:

Tank bottom linings can generally be divided into two (2) classes:

- a. Thin films (20 mils or less).
- b. Thick films (greater than 20 mils).

- NOTES:**
1. Linings are installed at tank erection or after some period of service.
  2. Generally, thin-film is applied when some minimal corrosion has occurred.
  3. Other liner discussion includes:

## 6.2 Thin-film types

Frequently based on epoxy or epoxy-copolymer resins. See Table 1 (Lining Systems) for generic types and their suitability for various services.

**NOTE:** All linings that are employed to protect tank bottoms must be **resistant to water**.

### 6.2.1 Advantages - Disadvantages (Thin Film Type)

- a. Advantages:
  - i. New plate provides a smooth surface that can easily be made ready for coating application.
  - ii. Lower cost (due to ease of application).
- b. Disadvantage:
 

Corrosion creates a rough/pitted surface that is difficult to completely coat and protect.

### 6.3 Thick-Film types

Commonly reinforced with glass flake, chopped glass fibers, glass mat, glass cloth or organic fibers.

- a. Generic types and where used. (See Table 2)

**NOTE:** Additional data available in NACE Publication 6A187.

- b. Specific notes relative to thick-film types:
  - i. All applied over a white or near-white abrasive blast.
  - ii. Primer frequently required.
  - iii. Dependent upon thickness required - multiple coats needed.
  - iv. Resin-rich topcoat required.
  - v. Polyesters require wax addition to ensure timely cure.
  - vi. Check with manufacturer for specifics (chemical immersion, elevated temperature tolerance, limitations in specific products, etc.).

#### 6.3.1 Advantages (thick-film types):

Advantages:

- a. Less susceptible to mechanical damage.
- b. Provides additional strength to bridge over small bottom perforations.
- c. Not as sensitive to pitting and other surface irregularities during installation.
- d. Less need for removal of sharp corners, edges, offsets and weld spatter.

#### 6.3.2 Disadvantages (thick-film types):

Disadvantages:

- a. Require more time and effort to apply.
- b. More expensive.
- c. Makes future inspections more difficult.

### 6.4 Design of Storage Tank Bottom Linings



- a. Normal data or knowledge required:
  - i. Linings should extend 18-24 inches up the shell.
  - ii. Transition area (from bottom horiz. to shell vert.), is a common failure area. Proper support, especially with thick-films are critical in this area.
  - iii. With thin-film types, desired film thickness normally requires 2-3 coats.
  - iv. Thick-films range from 1-4 coats.
  - v. New tanks, or where **only** internal loss has occurred may require 35-55 mils.
  - vi. Older bottoms, corroded on **both** sides may require 80-120 mils (usually reinforced).
  
- b. More specific data:
  - i. "**White**" (SSPC-SP5/NACE #1) or a "**near-white**" (SSPC-SP10/NACE #2) abrasive blast cleaner.
  - ii. Anchor pattern (surface roughness) required is generally between 1.5 and 4 mils, depending on lining selection.

## 6.5 Exceptional Circumstances Affecting Selection

Be sure to take into consideration:

- a. Corrosion history **or** corrosion potential
- b. Elevated temperatures. **Above 160°F** is critical.
- c. Product purity. Thin-films may be sufficient.
- d. Liner may contaminate product.

**NOTE:** NACE Publ. TMO174 or Military Spec MIL-C-4556D may be of assistance if manufacturer cannot furnish special data.

## SECTION 7 - SURFACE PREPARATION

## 7.1 General

- a. Surface preparation is a critical part of lining operation. Surface preparation is performed to provide the appropriate combination of surface cleanliness/surface profile (anchor profile) required to establish good chemical and mechanical adhesion of the coating resin to the substrate (i.e., steel). Inadequate surface preparation is a major cause of lining failure. However, a well prepared surface becomes meaningless if all of the abrasive material (i.e., sand, etc.) is not removed prior to primer/liner application. In such event, a lack of adhesion, future peeling or disbonding failure can be expected.
- b. Continuous immersion presents a severe exposure.

**NOTE:** SP5 #1 (white metal finish) or SP10 #2 (near-white) is often specified as the **minimum** degree of surface cleanliness.

## 7.2 Precleaning

- a. Before blasting, **all** contaminants (i.e., oil, tar, grease, salt, etc.) must be removed.
- b. Solvent cleaning (SSPC-SP1), high pressure water or steam cleaning should be considered. Fresh water wash after solvent cleaning, may be required to remove soluble salts and cleaning chemicals.

## 7.3. Bottom Repair - Weld Preparation

- a. Most common repair of perforations is welded steel patches. Another repair method is to epoxy a 12 gauge steel plate over the bottom perforation **prior to** thick-film (reinforced) linings being installed.

**SAFETY NOTE:** Weld repair **may be disallowed** if tank pad has been contaminated with flammable materials.

- b. Remove sharp edges, corners and protrusions. Chipping or power grinding most common removal method.

## 7.4 Abrasive Blasting

**Do Not Blast** when steel temperature is less than 5°F(3°C) above the dew point **or** if the relative humidity is greater than 80%. In particularly humid areas, such as coastal regions, potential solutions might be selective timing, which may influence work schedules, or perhaps the use of forced air injection.

**NOTE:** Liner applications **must** be conducted **when** surface condition is appropriate. Delay (between blast and application) will produce poor results. **When in doubt**, restore surface preparation to the necessary degree.

## 7.5 Surface Profile or Anchor Pattern

- a. Match profile to accommodate selected liner.
- b. Refer to material manufacturer's recommendation.
- c. Typical anchor pattern is 1.5 to 4 mils. This generally increases with liner thickness.

## 7.6 Types and Quality of Abrasives

# SECTION 8 - LINING APPLICATION

## 8.1 General

- a. Avoid disbonding or delamination by following manufacturer's recommendations.
- b. Stick to **time interval** (between coats) recommended by owner's specifications or manufacturer.
- c. SSPC-PA1 is a dependable procedure to follow.
- d. Establish and adhere to recommended drying (curing) period. Customers often get impatient.

## 8.2 Application Guidelines

- a. SSPC-PA1 and NACE 6F164 - Good painting practice.
- b. Establish and adhere to proper mixing practices.
- c. If conflicts arise (between owner / user; liner applicator or material manufacturer) over any aspect of the job, **resolve them prior** to beginning the project.
- d. Consider restraints imposed by steel temperature and relative humidity.

## 8.4 Lining Thickness

- a. Insufficient film thickness will not provide adequate coverage or protection.
- b. Excessive thickness can compromise adhesion and integrity. **Thicker is not always better.**

## 8.5 Lining Curing

- a. Lining failure is attributed to:
  - i. Improper preparation.
  - ii. Improper application.
  - iii. Inadequate curing.

**NOTE:** Adhesion and film integrity depend upon above listed items.

- b. Proper curing conditions may be aided by force-curing (i.e., circulating warmed, dehumidified air).

<b>Notes</b>
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**API RP 652  
(Reinforced Glass-epoxy Internal Lining 65 Mils Thick)**

Clean and repair the tank bottom (install lap weld steel plate patches 3/16" or 1/4" and weld build-up).

Abrasive blast per API 652 specifications, remove all residue (air blow, broom sweep and vacuum) remove all moisture.

Hand trowel epoxy in the corner area and radius all transitions, and around patch plates.

Consult a "Technical Representative" for the product being installed, include a job site visit.

If the following conditions are correct:

- Proper blast profile
- Proper material mixture
- Application equipment properly functioning
- Material specifications correct
- Proper thickness applied
- Proper curing procedure followed
- Weather restraints are observed

**The lining will be satisfactory and last 10 - 20 years.**

**SECTION 9 - INSPECTION**

Items 7.1 (General) through 7.3.2.4 (Discontinuities) list some qualifications, parameters and procedures to assist or guide in the area of Inspection. Without going into detail or explanation, some or all of the following should provide guidelines or assistance.

**9.2 Personnel NACE certified**

**9.3 Recommended Inspection Parameters**

Refer to NACE RP-02-88

**9.3.1.2** Cleanliness and Profile: Refer to SSPC-VIS1 (reference photos) and NACE TMO175 (sealed steel reference panels) NACE RPO287 provides a method of measuring surface profile.

**9.3.1.3** Film thickness

- a. Soon after application, **wet film** "t" measurement should be made. Refer to ASTM D4414.
- b. After curing, **dry film** "t". Refer to SSPC PA2.

**9.3.1.4** Hardness: As applicable, refer to the following procedures:

- a. ASTM D 2583
- b. ASTM D 2240
- c. ASTM D 3363
- d. Solvent wipe test

**9.3.1.5** Discontinuities

- a. Linings exceeding 20 mils "t" shall be holiday tested with a high voltage detector (see NACE RPO188).
- b. Linings less than 20 mils should be tested with a low voltage (67.5 volts) wet sponge detector.

## SECTION 10 - REPAIR OF TANK BOTTOM LININGS

### 10.1 General

- a. Properly selected / applied liners should provide a service life of 10-20 years.
- b. Any bottom mechanical repair should be complete prior to any liner installation or repair.

### 10.2 Determine Cause of Failure

Before deciding **how** to make a lining failure repair, the **cause** or **extent** should be established by visual inspection and a review of the operating history. Attempt to determine if:

- a. Failure was due to mechanical damage.
- b. Environmental attack was responsible.
- c. Improperly installed.

### 10.3 Types of Repair

- a. Spot repairs for localized failure (blisters, pinholes or mechanical damage)
- b. Topcoating for more extensive failure but where adhesion and integrity is still good. **Make sure** topcoat is compatible with existing liner.
- c. Complete replacement when existing liner is beyond repair.

## SECTION 11 - SAFETY

## 11.2 Tank Entry

Permits for tank entry and hot work should be issued and enforced. Follow guidelines for issuing permits and preparing a tank or confined space for entry, as detailed in API Publication 2015.

## 11.3 Surface Preparation and Lining Application

Use respiratory equipment and protective clothing as found in:

- a. OSHA Standard for Abrasive Blasting.
- b. SSPC PA 3.
- c. NACE 6D163.
- d. Any relevant federal or state regulation.
- e. As required on tank entry permit.

## 11.4 Manufacturer's Material Safety Data Sheets

- a. Indicates the "**chemical make-up**" that can present health hazards to personnel.
- b. MSDS inform about materials so that they can protect themselves and how to respond properly to emergency situations.
- c. Purpose of MSDS is to inform personnel of:
  - i. A Material's physical properties which make it hazardous to handle.
  - ii. The type of personal protective equipment needed.
  - iii. First aid treatment necessary ( if exposed).
  - iv. Safe handling under normal conditions and during emergencies such as fires and spills.
  - v. Appropriate response to accidents.

## API-652 (LINING TANK BOTTOMS) "QUIZ"

1. Which of the following pertains to or establishes the "**dew point**"?
  - a. Difference (in °F) between the relative humidity value and the internal tank air temperature.
  - b. Difference (in °F) between the internal tank air temperature and the substrate (steel) temperature
  - c. The temperature at which moisture condenses from the atmosphere.
  - d. The moisture content value at which adhesion between the liner and the substrate cannot be achieved.
  
2. Indicate the most correct definition for "**a holiday**".
  - a. A lamination that develops between coating layers.
  - b. A discontinuity in a coating film that exposes the metal surface to the environment.
  - c. Any thin liner area where an additional film "t" layer is required.
  
3. \_\_\_\_\_, \_\_\_\_\_ and \_\_\_\_\_ are common examples of aromatic solvents.
  
4. A \_\_\_\_\_ is an oxide layer formed on steel during hot forming operations.
  
5. There are five (5) common mechanisms normally associated with internal tank bottom corrosion. List any three (3) of the five (5) causes below.
  - a. \_\_\_\_\_
  - b. \_\_\_\_\_
  - c. \_\_\_\_\_
  
6. Match the following SSPC surface preparation to the metal finish specification, as specified in Section 5. **Draw Arrow to Connect.**

White Metal Finish	SSPC-SP5 NACE #1
Near-White Metal Finish	SSPC-SP10 NACE #2

7. Select the **general rule** normally followed relative to liner application vs. temperature and humidity restrictions.
- a. 5°F (3°C) above dew point, with relative humidity below 80%
  - b. 10°F (5.5°C) above dew point, with relative humidity below 80%
  - c. Stop application when visually, adhesion and bonding is not being achieved.
  - d. Any substrate temperature when moisture is visible.
8. What is the **typical** range required on anchor pattern (i.e., depth profile) prior to liner installation.

**Answer:** \_\_\_\_\_

9. \_\_\_\_\_ is a natural or synthetic substance that may be used as a **binder** in coatings.
10. When considering the need for an internal lining, make selections from below as some of the more important.
- A.
    - a. Where is corrosion occurring?
    - b. How fast is it proceeding.
    - c. Have there been significant corrosion rates changes.
    - d. What type of corrosion is occurring.
    - e. Have bottom perforations occurred.
  - B. Sub-items "b", "c" and "d" only.
  - C. All of the above.
  - D. Primarily cost and out-of service time frame involved.



## API 652 CODE QUIZ

### ANSWER KEY

1. "c" (Temperature at which moisture condenses from atmosphere).
2. "b" (Discontinuity exposing surface to environment).
3. Benzene, Toluene and Xylene.
4. Mill Scale
5. Any of the following:
  - Chemical Corrosion
  - Concentration cell corrosion
  - Galvanic Cell Corrosion
  - Erosion Corrosion
  - Corrosion caused by sulfate-reducing bacteria.
6. White ----- SP5 #1  
Near-White ---- SP10 #2
7. "a" (5°F above dew point with relative humidity below 80%).
8. 1.5 to 4 mils
9. Resin
10. A - All 5 considerations.



## **Section 6**

### **API Publication 2207 – Preparing Tank Bottoms for Hot Work**

## API PUBLICATION 2207

### PREPARING TANK BOTTOMS FOR HOT WORK

FIFTH EDITION - SEPTEMBER 1998

#### PREFACE

This publication outlines safety precautions for preventing accidental fires and explosions when hot work is performed on tank bottoms.

#### SECTION 1 - GENERAL

##### 1.1 Introduction and Scope

- a. The term **hot work**, as used here, is defined as an operation that can produce a spark or flame hot enough to ignite flammable vapors.
- b. Tanks that have contained flammable or combustible liquids, regardless of age or type, **must be** considered unsafe for hot work until safety inspections prove otherwise.
- c. A primary consideration is that the oxygen content **must be** between 19.5% and 22.5%.

#### SECTION 3 - PRECAUTIONS

##### 3.1 General Precautions

- 3.1.1 The tank must be **isolated, cleaned, ventilated** and **tested** for toxic and flammable vapors, plus oxygen deficiency.

**NOTE:** Test in accordance with applicable national, state and local regulations, plus recognized industry practices (i.e., OSHA Part 1910 and API Publications 2015 and 2217.

##### 3.1.2 and 3.1.3

The following is required prior to hot-work:

- a. Visual survey of area.
- b. Trained, experienced person to authorize hot-work.
- c. Precautions designated.
- d. First aid and fire-fighting equipment.
- e. Personnel instructed in use of equipment.

##### 3.2 Specific Precautions

- 3.2.1 Permits (i.e., job, entry, work): signed and issued.
- 3.2.2 Appropriate air mover in operation continuously.

- 3.2.3 Attached pipe systems disconnected, blanked off or isolated during all entry or hot-work.
- 3.2.4 Leaded surfaces should be scraped down to bare metal **or**, alternatively, supplied air respiratory equipment can be used. For surfaces that are to be excessively heated, an area of at least 12" (30 centimeters) should be scraped down to bare metal on all sides.

**NOTE:** Scraping may be waived **if** frequent air-quality tests indicate a safe atmosphere. This applies **only** to other personnel in area. If not scraped, **Welders** must wear supplied air respirators.

- 3.2.5 Grounding leads from welding machine should be attached directly to **bare** tank shell surface. Also, welding leads to be checked for abrasions, cuts, scuffs or breaks.

3.2.6 Cutting equipment

- a. Compressed-gas cylinders: Fastened in an upright position and located outside the tank manhole.
- b. Cutting torches/hose (when not in use): Closed-off at cylinder and kept outside tank.
- c. Gas supply hoses: Protected from outside damage and from internal source of problems (i.e., burns, cuts or breaks).

3.2.7 Periodic Checks

All work areas must be monitored for oxygen deficiency or combustible or toxic atmospheres.

## SECTION 4 - INSPECTION PROCEDURES

### 4.1 General

When repairs are planned, tank bottom **must** be inspected, regardless of its suspected condition.

### 4.2 Specific Procedures

- a. Holes cold-cut or drilled (in hot-work area) to provide an underside inert atmosphere and should be monitored. Apply coolant when installing hole. **Do not** use an electric drill.
- b. Oil-soaked insulation (ext. hot-work) should be removed. Determine type so it can be handled properly.

## SECTION 5 - SAFE WORK PROCEDURES

### 5.1 General

Safe work procedures should be written and approved by a competent, trained or experienced person. The work procedures adopted will depend on:

- a. The tank bottom condition.
- b. The type and extent of the hot work repairs.
- c. The inspection results (at the bottom).

### 5.2 Minor Repairs

- a. Usually consist of welding corrosion pits, installing patches or welding supports or braces.
- b. To establish a below bottom inert atmosphere:
  - i. Drill or tap a 1/2" pipe size hole in bottom.
  - ii. Connect a supply of CO<sub>2</sub> (or other inert gas) to the 1/2" nipple with metal tubing. A pressure control valve with a flow indicator should be used to prevent bottom overpressure.
  - iii. Prior to hot work, establish a flow of inert gas under the bottom in the vicinity of the hot-work.
  - iv. Continuously monitor oxygen content.
  - v. When hot-work (local area) is complete, stop the inert gas flow.
  - vi. Remove the nipple and plug the hole with a tapered pin or other device and back weld promptly - **Before moving to another area.**

### 5.3 Major Repairs

When repairs involve most of the tank bottom, it may be desirable to displace the flammable liquids beneath the tank by water flooding.

- a. Construct an earthen dike.
- b. Drill or tap bottom vent holes. (and/or couplings).
- c. Install vent pipe nipples.
- d. Fill dike and allow for complete water coverage on underside.
- e. Watch for bottom leaks. Plug-stop as necessary.
- f. When repairs are complete, remove vents, plug and weld.
- g. Break water dike.

### 5.4 Perimeter Repairs

- a. Excavate under the tank for a minimum of 12" beyond the hot-work area.
- b. Monitor for oxygen content.
- c. Seal-off between bottom plate and foundation by mud-packing or other non-corrosive material.
- d. Check for explosive or toxic vapor in excavation.
- e. Monitor for airborne concentrations of chemical contaminants.
- f. As necessary, ventilate with a portable air blower.
- g. Back-fill and compact excavation to prevent future damage to foundation.

## 5.5 Double Bottoms

Install 4" (10 centimeters) of sand or other sealing material over the existing bottom.

Install new bottom by welding.

**NOTE:** This is a poor practice

## 5.6 Sectional Repairs

When sectional repairs are made on tank bottoms, the following methods may be used:

- a. Cold-cut segment to be replaced. Remember, a coolant should be applied continuously to the cutting edge of the tool to reduce the heat of friction.
- b. Remove the sand from the area of replacement and refill with tamped sand. Seal the perimeter area.
- c. Monitor for oxygen deficiency and combustible or toxic atmospheres.
- d. Larger areas should be inert gas blanketed while patch is being installed.

**API - PUBL. 2207**  
**"QUIZ"**

1. Of the following, which is the correct range of oxygen content necessary for entry into confined spaces (without special breathing equipment)?
  - a. 18.0 to 20.0%
  - b. 19.0 to 21.0%
  - c. 19.5 to 22.5%
  - d. 20.0 to 23.0%
  
2. As used in this Publication, which of the following best describes the term "Hot Work"?
  - a. Any external heat greater than 200°F.
  - b. An operation producing a spark or flame hot enough to ignite flammable vapors.
  - c. Weld arcs, air arcs or cutting torches only.
  - d. Any external or internal heat greater than 200°F.
  
3. When scraping metal (with lead contamination) where excessive heating will be applied, what is the **minimum** measurement (away from the heat area) recommended?
  - a. 12" on each side of heat line.
  - b. 24" on each side of heat line.
  - c. 24" diameter circle around outside edge of heat line.
  - d. Dependent on tested lead contamination value.
  
4. While work is in progress (inside tank), all work areas must be monitored for oxygen deficiency and \_\_\_\_\_.
  
5. Which **specific** inert gas is suggested for injection under tank bottom when hot-work is in progress?
  - a. Nitrogen
  - b. Oxygen
  - c. Helium
  - d. Carbon dioxide

## API PUBL. 2207 QUIZ

### ANSWER KEY

1. "c" (19.5 to 22.5%)
2. "b" (spark or flame that will ignite flammable vapors).
3. "a" (12" on each side of heat line).
4. Combustible and toxic atmospheres
5. "d" (carbon dioxide) i.e., CO<sub>2</sub>.





## **Section 7**

### **API 2015 – Safety Entry & Cleaning Petroleum Storage Tanks**

**API Standard 2015  
Sixth Edition, August 2001**

**SAFE ENTRY AND CLEANING OF PETROLEUM STORAGE TANKS**

*This new Edition contains many changes and introduces API RP 2016, which was information contained within API 2015*

**SECTION 1 - GENERAL**

**1.1 Scope and applicability**

This standard is applicable to cleaning stationary atmospheric and low-pressure (up to and including 15 psig) ASTs.

**1.2 Non-applicability and other tank cleaning applications**

The tanks that this standard does not apply is listed here.

**1.3 ANSI/API Recommended Practice 2016**

**A large section of the Fifth Edition of API 2015 is now in this Recommended Practice.**

**1.4 Regulatory Requirements**

This standard is intended to be consistent with Title 29 of the U.S. Code of Federal Regulations (Occupational Safety and Health Administration). Other regulations, federal state local etc. may also apply and should be consulted.

**1.5 Tank cleaning overview**

This entire section outlines a method for thinking about, pre-cleaning, cleaning and post cleaning plans.

**SECTION 2 - REFERENCES**

## SECTION 3 - DEFINITIONS

*Note: The student should read each definition and have a basic working knowledge of the following.*

- 3.2.2 attendant:** A qualified employee stationed outside one or more permit required confined spaces who monitors the entrants and who performs all attendant's duties in accordance with the employer's (owner/operator and contractor) permit required confined space program. Attendants may also perform the duties of standby personnel when entrants use respiratory protective equipment.
- 3.2.3 blanking:** The absolute closure of a pipe or line by fastening a solid, flat plate (designed to retain the pressure of the pipeline), between two flanges, using two gaskets and fully engaged bolts or stud bolts in all flange bolt-holes. Blanks have handles extending beyond the flange with a 1/4-inch (6.3 mm) minimum hole in the handles (see ASME B31.3 for additional information).
- 3.2.4 blinding:** The absolute closure of the open end of a pipe, line or pressure vessel opening by fastening a solid, flat plate (designed to retain the pressure) across the opening, using a gasket and fully engaged bolts or stud bolts in all flange bolt-holes (see ASME B16.5 and B16.47 for additional information).
- 3.2.5 bonding:** The joining of metal parts to form an electrically conductive path that ensures electrical continuity and has the capacity to safely conduct any current likely to be generated.
- 3.2.8 combustible liquid:** A liquid having a closed cup flash point equal to or greater than 100°F (38°C).
- 3.2.9 confined space:** Any tank or space that meets *all three* of the following requirements:
- \*Is large enough and so configured that an employee can bodily enter and perform assigned work, and
  - \*Has limited or restricted means for entry or exit (for example, tanks and vessels, storage bins, hoppers, vaults, and pits are spaces that may have limited means of entry or exit), and
  - \*Is not designed for or meant to be continuously occupied by employees.
- 3.2.9.1 permit-required confined space:** A confined space that *has all three* of the confined space requirements and also has *one or more* of the following four characteristics:
- \*Contains or has the potential to contain a hazardous atmosphere.
  - \*Contains a material with the potential to engulf an entrant.
  - \*Has an internal configuration such that an entrant could become trapped or asphyxiated by inwardly converging walls or by floors that slope downward, tapering to smaller cross-sections.
  - \*Contains any other recognized serious safety or health hazard.

**3.2.9.2 non-permit required confined space:** A confined space (a space that meets *all three* of the confined space requirements) but has been checked, inspected and its atmosphere has been monitored and it does not have (or does not have the potential to have) any of the characteristics required to be classified as a permit required confined space.

**3.2.9.3 non-confined space:** A space (previously classified as a permit required confined space or a non-permit required confined space) that no longer meets any of the requirements for either a permit required confined space or a non-permit required confined space.

**Note:** An example of a non-confined space is a tank that has been cleaned, tested as gas and vapor free and has a large opening (door sheet) cut into the side of the tank to provide unrestricted access and egress.

**3.2.11 double block and bleed:** The positive closure of a line or pipe by closing and locking or tagging two in-line valves and by opening and locking or tagging a drain or vent valve in the line or pipe between the two closed valves.

**Note:** Employers may evaluate and designate a single valve that uses two sealing surfaces within a drain orifice between them as satisfying double block and bleed requirements.

**3.2.15 employer:** An owner, operator, contractor, or subcontractor whose respective employees are performing a task, or activity described in this standard.

**3.2.15.1 owner/operator:** The company or person responsible for the facility in which the tank to be cleaned is located.

**3.2.15.2 contractor:** A company or person selected and hired by the owner/operator to conduct tank cleaning operations and activities in accordance with the contract and tank cleaning agreements. There may be more than one contractor on a job at the same time.

**3.2.15.3 sub-contractor:** A company or person selected and hired by a contractor to conduct specific tank cleaning related operations and activities in accordance with sub-contract agreements. There may be more than one sub-contractor on a job at the same time.

- 3.2.21 entry supervisor:** The qualified person (employee, foreman, supervisor, crew chief, etc.) designated by the employer (owner/operator and contractor) to be responsible for determining the requirements and whether or not acceptable entry conditions exist at permit required confined spaces and non-permit required confined spaces, where entry is contemplated. Entry supervisors shall authorize entry, oversee entry operations and terminate entry as required by the permit or conditions. An entry supervisor, who is properly qualified, trained and equipped, may serve as an attendant or as an entrant. The duties of entry supervisor may be passed from one entry supervisor to another entry supervisor, during the course of an entry operation.
- 3.2.24 flammable liquid:** A liquid having a closed cup flash point below 100°F (38°C).
- 3.2.32 hot work:** Any work that has the potential to produce enough thermal energy to provide an ignition source in an area where a potential exists for a flammable gas or vapor-in-air atmosphere in the explosive (flammable) range to occur.
- 3.2.34 immediately dangerous to life or health (IDLH):** Any condition that poses an immediate or delayed threat to life or that would cause irreversible adverse health effects or that would interfere with an entrant's ability to escape unaided from a permit required confined space. For example, an oxygen deficient atmosphere is considered IDLH. Some toxic materials, such as hydrogen fluoride gas and cadmium vapor, may produce immediate transient effects that even if severe, may pass without medical attention, but are followed by sudden, possibly fatal collapse 12 to 72 hours after exposure. The exposed worker "feels normal" from recovery from transient effects until collapse. Such materials in hazardous quantities are considered to be "immediately" dangerous to life or health (IDLH). Other toxic substances, such as hydrogen sulfide, immediately desensitize a person so that continued exposure is not longer noticed. Certain irritation effects may also impede the entrant's ability to escape permit required confined spaces.
- 3.2.39 lockout/tagout:** The condition when electrical, hydraulic and mechanical switches are open in the de-energized position and locked out and/or mechanical linkages are set, tagged and sealed or locked out to preclude the input of product or energy into a permit required confined space, non-permit confined space or non-confined space. Where required by regulation or employer procedures, the system shall be tested to assure isolation.
- 3.2.40 material safety data sheet (MSDS):** Written or printed material prepared in accordance with applicable regulations and standards (for example, OSHA 29 CFR 1910.1200) concerning hazardous chemicals. MSDSs provide physical properties, safety, fire prevention and protection, personal protection, and health data.
- 3.2.50 product:** The liquid petroleum hydrocarbon or other material stored in tanks.
- 3.2.52 pyrophoric iron sulfide:** A material capable of rapid spontaneous ignition when exposed to air.

- 3.2.54 qualified person:** A person designated by an employer (owner/operator and contractor) as having the necessary training, education and competence to perform assigned tank cleaning and entry related tasks or activities in accordance with the employer's (owner/operator and contractor) policy, procedures, and programs.
- 3.2.70 worker:** A qualified person working in or around a tank during tank cleaning. A worker, working inside a tank, may or may not be an entrant depending on the classification of the tank.

## **SECTION 4 - ADMINISTRATIVE CONTROLS AND PROCEDURES**

### **4.1 General Requirements**

The owner, operator, or contractor must develop written plans for all tank work.

### **4.3 Qualified Persons**

Qualified persons are: testers, entry supervisors, hot and cold work permit issuers, attendants, entrants, standby persons, workers and rescuers.

## **SECTION 5 - PREPARING THE TANK FOR ENTRY AND CLEANING**

A general plan for cleaning the tank, including MSDS, special requirements, decommissioning and returning the tank to service.

## **SECTION 6 - TESTING THE TANK ATMOSPHERE**

The tank must be tested, by a qualified person, for oxygen levels, combustible gas, toxic substance, and general atmosphere.

## SECTION 7 - STORAGE TANK HAZARDS

### 7.1 General

"All" tanks present one or more of the following hazards during some phase of tank entry and work:

- a. Fires and explosions.
- b. Oxygen deficiency
- c. Toxic liquids, vapors and dust.
- d. Physical and other hazards.

### 7.2 Oxygen Deficiency

- NOTES:**
1. Internal atmosphere may be stratified (i.e., layered).
  2. Potential hazards:
    - i. Fire and asphyxiation
    - ii. Toxic substances.
  3. **"Sneaky"** Oxygen deficiency is usually not noticed and little or no warning is given. The effects are compounding (i.e., loss of reasoning ability, followed by unconsciousness).

### 7.3 Fire and Explosion Hazards

### 7.4 Toxic substances

- a. Can cause injury, acute or delayed illness or death.
- b. Toxicants can enter the body by inhalation, ingestion and skin contact (including eyes).
- c. Toxic substances occur in several forms:
  - i. Irritants - minor, transient, but possibly painful. Many hydrocarbons/polar solvents are irritants.
  - ii. Corrosives - destroy tissue/leave permanent scars. These include hydrofluoric acid, sulfuric acid, caustics.
  - iii. Acutely toxic - single dose/short term exposure. The results of exposure to these toxins i.e., hydrogen sulfide (H<sub>2</sub>S) range from headache or nausea to disablement or death.
  - iv. Chronically toxic - physiological impairment with long latency such as cancer, pulmonary obstruction or reproduction.
- d. Toxic substances which are likely to be found in entering and clearing petroleum storage tanks are:
  - i. H<sub>2</sub>S
  - ii. Leaded gasoline
  - iii. Dusts
  - iv. Petroleum substances
  - v. Welding fumes
  - vi. Various chemical hazards



## SECTION 8 - HAZARD ASSESSMENT FOR ENTRY PERMITS

### 8.1 General

After testing for flammable vapors, oxygen content and toxic substances, tank entry conditions will fall into one of the following categories:

permit required confined space  
Non-permit required confined space

#### 8.2.1.1 Permit Required Confined Space

1. Has potential to contain hazardous atmosphere.
2. Contains a material with the potential to engulf an entrant.
3. Physical hazards or asphyxiate hazards.
4. Any other safety or health hazard.

#### 8.2.1.2 Non-Permit Required Confined Space

1. Large enough that entrants can enter and work.
2. Limited means for entry or exit.
3. Not designed to be continuously occupied by employees.

### 8.3 Entry into Tanks Classified as Permit Required Confined Spaces

The rules for permit required spaces are listed in these paragraphs.

### 8.4 Entry into Tanks Classified as Non-Permit Required Confined Spaces

The rules for non-permit required spaces are listed in these paragraphs.

## SECTION 9 - PERSONAL PROTECTIVE EQUIPMENT

This section covers:

- a. Clothing
- b. Shower facilities
- c. Respiratory protection
- d. OSHA Regulations
- e. Breathing air
- f. Air lines
- g. Fit testing
- h. Facepiece maintenance

## SECTION 10 - TANK CLEANING PERSONNEL

This section covers:

- a. Responsibilities
- b. Requirements
- c. Entry Supervisors
- d. Entrants
- e. Attendants
- f. Qualified Persons

## SECTION 11 - ENTERING AND WORKING INSIDE THE TANK

This section covers:

- a. Entry permit
- b. Ventilation
- c. Vapor and Gas sources
- d. Potential hazards

## SECTION 12 - HOT WORK AND TANK REPAIRS

### 12.1 General

If hot work is involved, the flammable vapor concentration **must not** exceed ten percent (10%) of the lower flammable limit.

**NOTE:** Hot work is **any work** that produces enough heat to be a **potential** ignition source (i.e., welding, burning, grinding, drilling and abrasive blasting).

### 12.2 Hot Work Permits

### 12.3 Hot Work Hazards

### 12.4 Hot Work in Leaded Service Tanks

### **SECTION 13 - EMERGENCY PLANNING**

No specific notes.

### **SECTION 14 - RECOMMISSIONING**

No specific notes.

### **SECTION 15 - TRAINING**

No specific notes.



## **Section 8**

**ASME Section V, Section VIII, Div. 1 –  
Nondestructive Examination**

# API 653 Nondestructive Examination

## API Paragraph 12.1.1.1

Nondestructive Examination procedures, qualifications and acceptance criteria shall be prepared for visual, magnetic particle, liquid penetrant, ultrasonic, and radiographic methods in accordance with API Standard 650 and the supplemental requirements given herein.

## API 653 Paragraph 12.1.1.2

Personnel performing nondestructive examinations shall be qualified in accordance with API 650 and the supplemental requirements given herein.

## API 653 Paragraph 12.1.1.3

Acceptance Criteria is based on API 650 and supplemental requirements of API 653.

## API 653 Paragraph 12.1.1.5

New Appendix G is introduced. The requirements for MFL, procedures, operator qualifications, training and equipment calibration is listed in this appendix.

## **API 653 uses API 650 requirements for nondestructive testing procedures and personnel certification.**

The American Society for Nondestructive Testing, Inc. Recommended Practice SNT-TC-1A is recognized for technician qualifications in some NDE techniques.

SNT-TC-1A is a document that outlines requirements for Personnel Qualification and Certification in Nondestructive Testing, the main items listed are:

- a. Work Experience
- b. Training
- c. Education
- d. Testing

In order to qualify as an ASNT Level II, Radiographers must have:

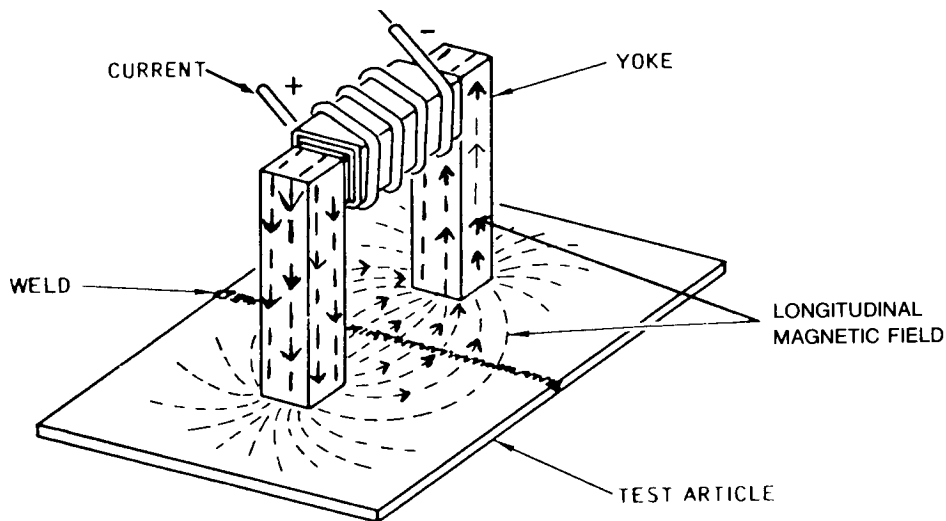
- a. 12 Months Job Experience
- b. 79 Hours Formal Training
- c. High School Graduation
- d. Level II Exam, General, Specific and Practical

In order to qualify as an ASNT Level II, Ultrasonic Technicians must have:

- a. 12 Months Job Experience
- b. 80 Hours Formal Training
- c. High School Graduation
- d. Level II Exam, General, Specific and Practical

**API 650 does not require MT or PT Technicians to be certified to ASNT-SNT-TC-1A.**

### Nondestructive Examination API 650 Magnetic Particle Method



### MT Principles of Operation

Basically, an object or localized area is magnetized through the use of AC or DC current. Once the area is magnetized lines of flux are formed, see above. Dry iron powder, or iron powder held in suspension is added to the surface of the test piece. Any interruption in the lines of flux will create an indication which can be evaluated. The process may be used on any material that is ferromagnetic. This method of NDE can be used in visible light or with special powders, under black light. Surface discontinuities are the most commonly detected indications using this process.

## **API 653 requirements**

### **API 653 directs the user to API 650 Paragraph 6.2.1 - 6.2.3**

When magnetic particle examination is specified, the method of examination shall be in accordance with the ASME Boiler and Pressure Vessel Code, Section V, Nondestructive Examination, Article 7.

### **API 650 Paragraph 6.2.2**

Magnetic particle examination shall be performed in accordance with a written procedure that is certified by the manufacturer to be in compliance with the applicable requirements of Section V, of the ASME Code.

### **API 650 Paragraph 6.2.3**

**No ASNT Certification Required, Manufacturer Determined  
Magnetic Particle Method Acceptance Standards per API 650**

### **API 650 Paragraph 6.2.4**

Acceptance standards and removal and repair of defects shall be per Section VIII, Appendix 6, Paragraphs 6-3 and 6-4, of the ASME Code.

### **ASME Section VIII, Appendix 6, Paragraph 6-3**

Definition of indication. Must be larger than 1/16".

### **ASME Section VIII, Appendix 6, Paragraph 6-4**

Acceptance Standards

All surfaces to be examined shall be free of:

- a. relevant linear indications;
- b. relevant rounded indications greater than 3/16"
- c. four or more relevant rounded indications in line separated by 1/16" or less, edge to edge.

### **API 650 Paragraph 6.2.4**

Acceptance standards and removal and repair of defects shall be per Section VIII, Appendix 6, Paragraphs 6-3 and 6-4, of the ASME Code.

### **ASME Section VIII, Appendix 6, Paragraph 6-3**

Definition of indication. Must be larger than 1/16".

**ASME Section VIII, Appendix 6, Paragraph 6-4**

Acceptance Standards

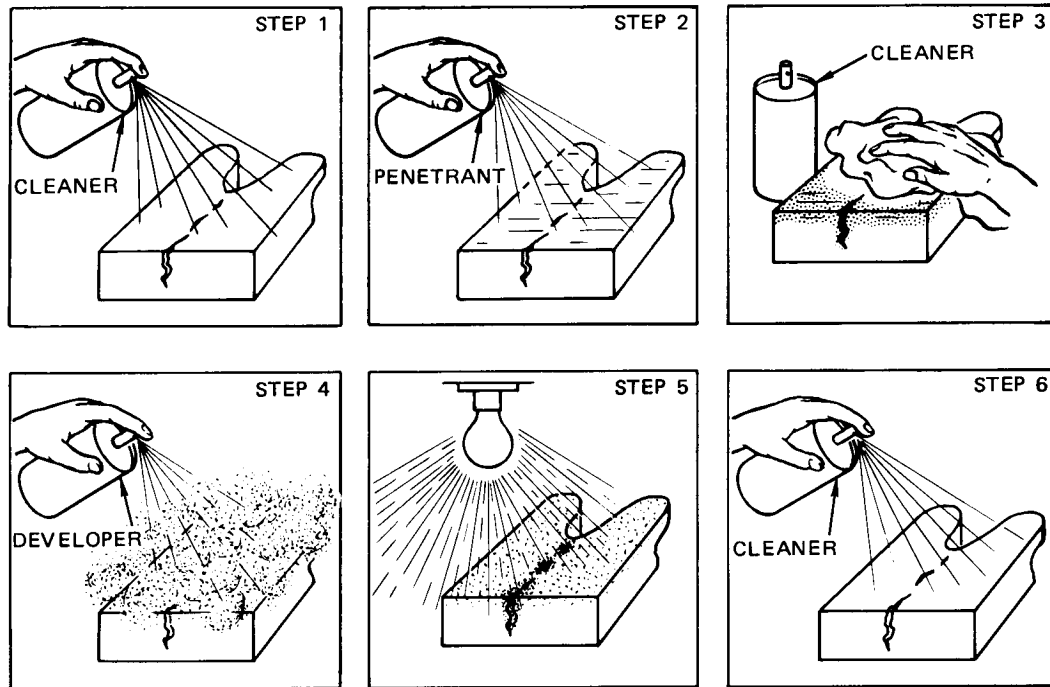
All surfaces to be examined shall be free of:

- a. relevant linear indications;
- b. relevant rounded indications greater than 3/16"
- c. four or more relevant rounded indications in line separated by 1/16" or less, edge to edge.

<b>Study Notes:</b>	<b>Page Number:</b>	<b>Standard/Code</b>
Know where to find:		
Calibration requirements	_____	_____
Yoke weight requirements, both AC and DC	_____	_____
General MT procedure requirements	_____	_____



**Nondestructive Examination  
API 650  
Liquid Penetrant Method**



**PT Principles of Operation**

Penetrant testing is a family of testing that can be divided into two major groups, visible light and fluorescent or “Black Light” detectable groups. The basic steps of the operation can be seen above. Step 1 the test piece must be cleaned. Step two the penetrant is applied, a dwell time or soaking time waited. Step three the excess penetrant is removed. Step four the developer applied. Step five the part is inspected, any indication is evaluated. Step six the part is post cleaned.

This inspection technique relies on the penetrant being pulled in to all surface irregularities by capillary action. When the developer is applied the penetrant is blotted back to the surface making the irregularities visible. The irregularities are then evaluated into three groups, false indications, commonly called handling marks, non-relevant indications and defects. The defects are evaluated to a given standard for acceptance.

This process will detect:

**Surface defects only!**

**Nondestructive Examination  
API 650**

**Liquid Penetrant Method**

**API 650 Paragraph 6.4.1**

When liquid penetrant examination is specified, the method of examination shall be in accordance with the ASME Boiler and Pressure Vessel Code, Section V, "Nondestructive Examination," Article 6

**API 650 Paragraph 6.4.2**

Liquid Penetrant examination shall be performed in accordance with a written procedure that is certified by the manufacturer to be in compliance with the applicable requirements of Section V, of the ASME Code.

**API 650 Paragraph 6.4.3**

No ASNT Certification Required, Manufacturer Determined

**API 650 Paragraph 6.4.4**

Acceptance standards and removal and repair of defects shall be per Section VIII, Division 1, Appendix 8, Paragraphs 8-3 , 8-4 and 8-5, of the ASME Code

**ASME Section VIII Division 1  
Liquid Penetrant Examination - Acceptability**

**Appendix 8 paragraph 8-3 Evaluation of Indications**

An indication is the evidence of a mechanical imperfection. Only indications with major dimensions greater than 1/16 in. shall be considered relevant.

- a. A linear indication is one having a length greater than three times the width.
- b. A rounded indication is one of circular or elliptical shape with the length equal to or less than three times the width.
- c. Any questionable or doubtful indications shall be reexamined to determine whether or not they are relevant.

**Appendix 8 paragraph 8-4 Acceptance Standards**

All surfaces shall be free of :

- a. relevant linear indications
- b. relevant rounded indications greater than 3/16"
- c. four or more relevant rounded indications separated by 1/16"

**Appendix 8 paragraph 8-5 Repair Requirements**

**Nondestructive Examination  
API 650**

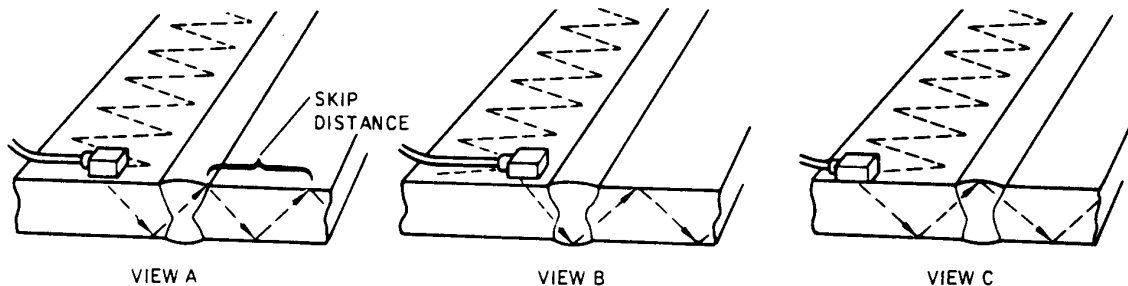
**Liquid Penetrant Method  
Study Notes**

Read ASME Section V, Article 6

<b>Study Notes:</b>	<b>Page Number:</b>	<b>Standard/Code</b>
Know where to find:		
Test temperatures	_____	_____
Surface temperatures	_____	_____
General PT procedure requirements	_____	_____

**Nondestructive Examination  
API 650**

**Ultrasonic Method  
(Weld Quality)**



**API 650 Paragraph 6.3.1**

Introduction of the new Appendix U. This appendix sets requirements for UT inspection when performed in lieu of radiography.

**API 650 Paragraph 6.3.2.2 (Ultrasonic requirements not in lieu of radiography)**

When ultrasonic examination is specified, the method of examination shall be in accordance with the ASME Boiler and Pressure Vessel Code, Section V, "Nondestructive Examination," Article 5.

**API 650 Paragraph 6.3.2.3**

Ultrasonic examination shall be performed in accordance with a written procedure that is certified by the manufacturer to be in compliance with the applicable requirements of Section V, of the ASME Code.

**API 650 Paragraph 6.3.2.4**

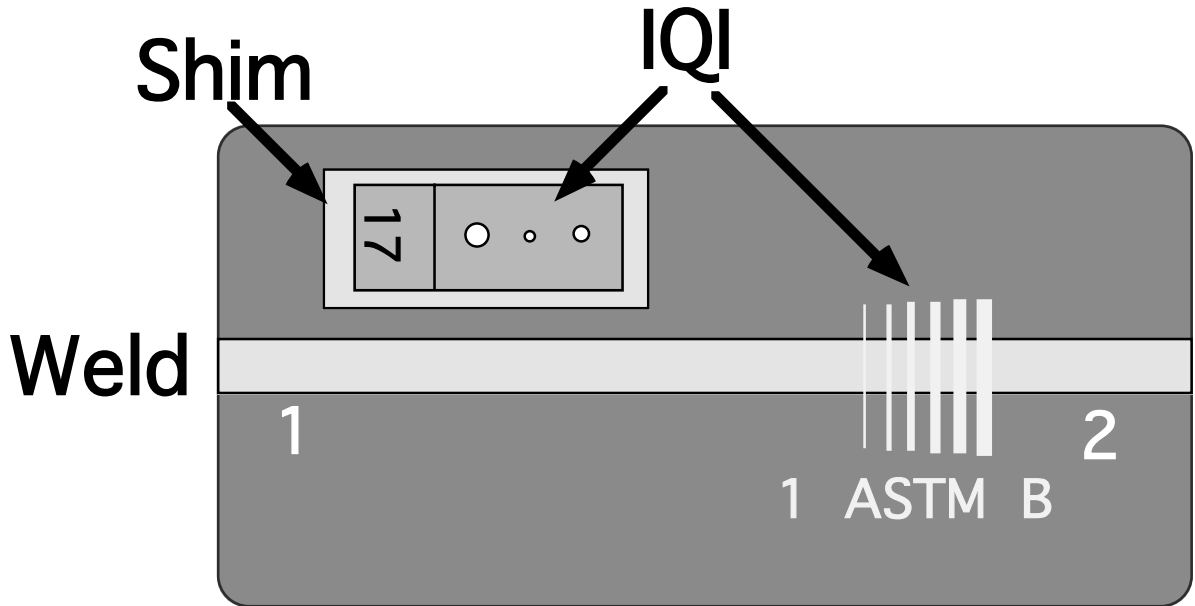
Examiners performing ultrasonic examinations under this section shall be qualified and certified by the manufacturers as meeting the requirements of certification as generally outlined in Level II or Level III of ASNT Recommended Practice SNT-TC-1A (including applicable supplements).

***Note: "Acceptance standards shall be agreed upon by the purchaser and the manufacturer." API 650 Paragraph 6.3.2.5***

The API 653 Effectivity Sheet has listed ASME Section V, Article 23 (Section SE-797 only). This section deals with "Standard Practice for Measuring Thickness by Manual Ultrasonic Pulse-Echo Contact Method". The section includes the general procedure requirements for thickness readings.

**Nondestructive Examination  
API 650**

**Radiographic Examination**



**API 650 Paragraph 6.1.3.1**

Except as modified in this section, the radiographic examination method employed shall be in accordance with Section V, Nondestructive Examination, Article 2., of the ASME Code.

**API 650 Paragraph 6.1.3.2**

Personnel who perform and evaluate radiographic examinations according to this section shall be qualified and certified by the manufacturers as meeting the requirements of certification as generally outlined in Level II or Level III of ASNT Recommended Practice SNT-TC-1A (including applicable supplements).

**API 650 Paragraph 6.1.3.3**

The requirements of T-285 in Section V, Article 2, of the ASME Code are to be used only as a guide. Final acceptance of radiographs shall be based on whether the prescribed penetrameter image and the specified hole can be seen.

## Radiographic Examination Acceptability

### API 650 Paragraph 6.1.5

The acceptability of welds examined by radiography shall be judged by the standards in Section VIII, Division I, Paragraph UW-51(b), of the ASME Code.

### UW-51 Radiographic and Radioscopic Examination of Welded Joints

(b) This section requires indications shown on the radiographs to be repaired. The repairs may be radiographed or optionally, examined by ultrasonic examination.

Indications that are unacceptable:

- Any crack
- Zone of incomplete fusion
- Zone of incomplete penetration
- Any other elongated indication which is longer than:

- 1/4 in for t up to 3/4 in
- 1/3 t for t from 3/4 in to 2 1/4 in
- 3/4 in for t over 2 1/4 in

### UW-51 Radiographic and Radioscopic Examination of Welded Joints (subparagraph 3)

Any group of aligned indications that have an aggregate length between the successive imperfections exceeds 6L where L is the length of the longest imperfection in the group.

Rounded indications in excess of that specified by the acceptance standards given in Appendix 4.

**Nondestructive Examination  
API 650**

**Radiographic Examination Study Notes**

Read ASME Section V, Article 2

<b>Study Notes:</b>	<b>Page Number:</b>	<b>Standard/Code</b>
Know where to find:		
Backscatter acceptability	_____	_____
Geometric Unsharpness	_____	_____
IQI information	_____	_____
Density	_____	_____
Location Markers	_____	_____
General RT procedure requirements	_____	_____



## **Section 9**

### **ASME Section IX – Procedures & Qualifications**



## API 653

### ASME Section IX

#### API 653 - Section 11 - Welding

11.1.1 Welding procedure specifications (WPS) and welders and welding operators shall be qualified in accordance with Section IX of the ASME Code. This includes welding procedure qualification records (PQR).

ASME Section IX is a document that outlines the requirements for welding procedures and welder qualifications. Other organizations that have the requirements for procedures are AWS (American Welding Society) and API (American Petroleum Institute) (API 1104). While both organizations have excellent rules, the only origination required by API 653 is ASME Section IX.

A welding procedure shows compatibility of:

- a. Base metals
- b. Filler metals
- c. Processes
- d. Technique

The general approaches to procedure qualification is usually in one of two forms:

- a. Prequalified procedures:

These are AWS welding procedures used only for structural welding and do not require testing. The user is limited to specific weld joints and specific weld processes (see AWS D 1.1).

- b. Procedure qualification testing:

These are API and ASME requirements. Both require actual welding to be performed and destructively tested.

ASME procedure qualification testing uses a listing of essential variables in the creation of weld procedures. Essential variables are those in which a change is considered to affect the mechanical properties of the weldment, and shall require requalification of the WPS, ASME IX Paragraph QW - 251.2.

Under ASME rules the welding procedure begins with the creation of the WPS. This information is taken from ASME IX and outlines the ranges of materials, electrodes and other general aspects. Then the PQR is created, performed and tested and used as proof for the WPS. The WPS can have many supporting PQRs.

Locations of weld specimens from plate procedure qualification.

Discard		this piece
Reduced-section		tensile specimen
Root-bend		specimen
Face-bend		specimen
Root-bend		specimen
Face-bend		specimen
Reduced-section		tensile specimen
Discard		this piece



QW-463.1 (a) Plates - Less than 3/4 in. Thicknesses Procedure Qualification

Discard		this piece
Side-bend		specimen
Reduced-section		tensile specimen
Side-bend		specimen
Side-bend		specimen
Reduced-section		tensile specimen
Side-bend		specimen
Discard		this piece



QW-463.1 (b) Plates - 3/4 in. and over Thickness and alternate from 3/8 in. but less than 3/4 in. Thicknesses Procedure Qualification

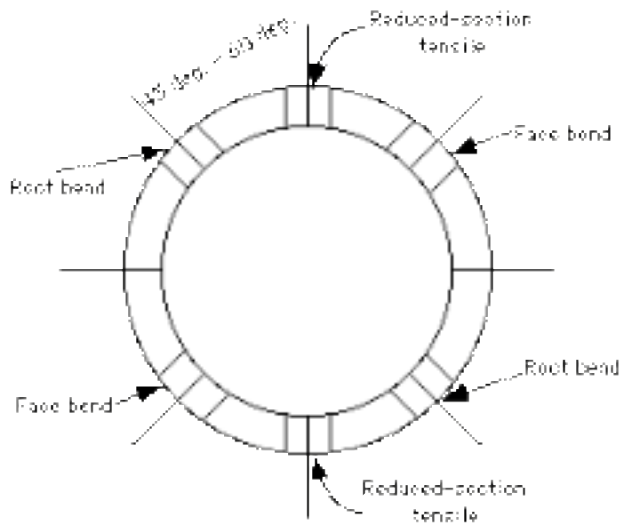
Discard		
		Longitudinal Face-bend Specimen
Reduced-section		tensile specimen
		Longitudinal Root-bend Specimen
		Longitudinal Face-bend Specimen
Reduced-section		tensile specimen
		Longitudinal Root-bend Specimen
Discard		



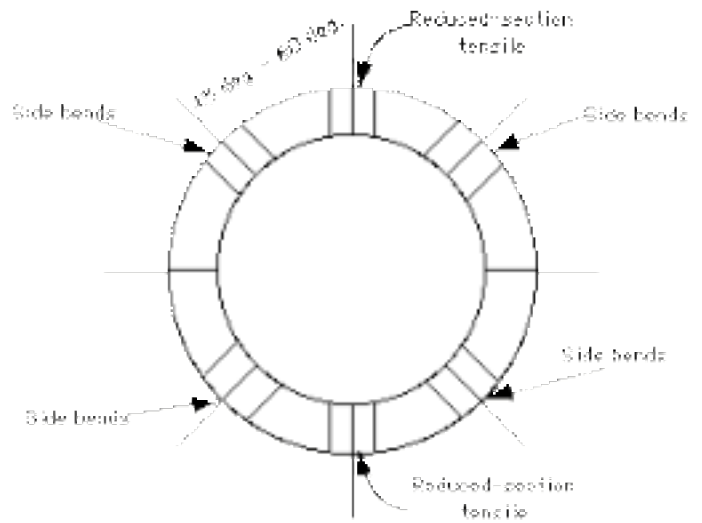
QW-463.1 (c) Plates - Longitudinal Procedure Qualification

Locations of weld specimens from pipe procedure qualification.

**QW-463.1 (d) Procedure Qualification**



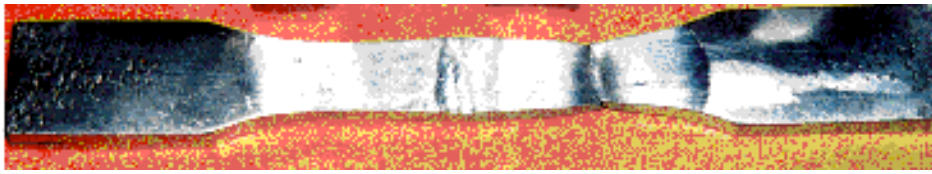
**Pipes - Less than 3/4 in. thickness**



**Pipes - 3/4 in. and over thickness and Alternate from 3/8 in. but less than 3/4 in. thickness**

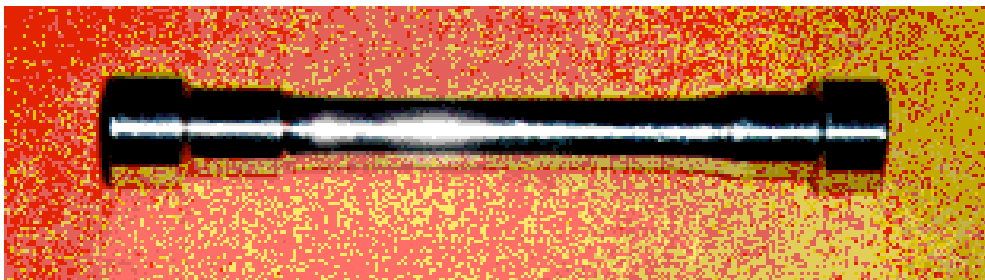
**QW-463.1 (e) Procedure Qualification**

Weld procedure specimens, guided bends are also used for welder qualification tests.



Square

## Tensile Specimens



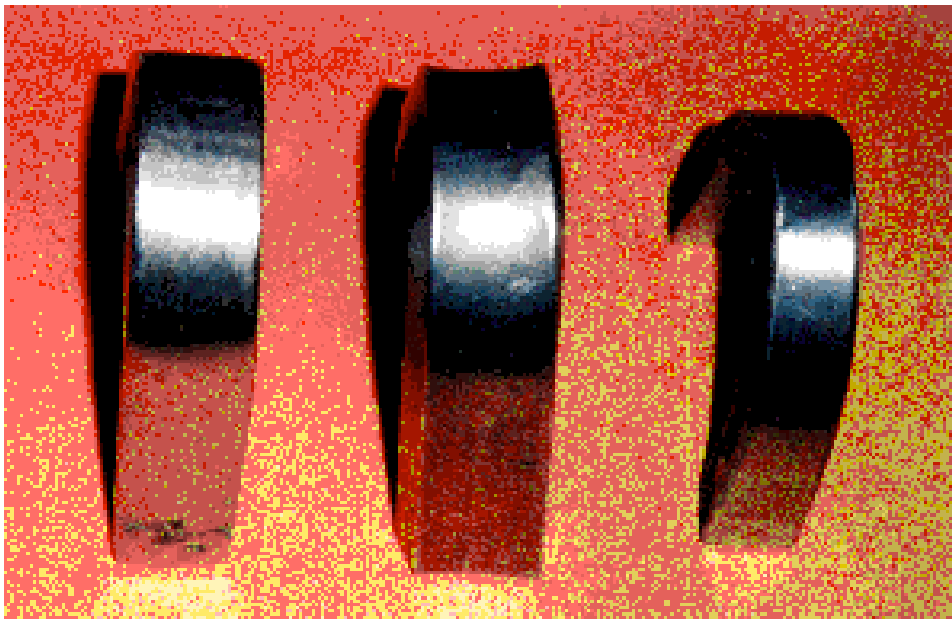
Round

## Guided Bends

Face

Root

Side



The tests commonly required by ASME Section IX are:

- a. Tensile
- b. Bends
  1. Face
  2. Root
  3. Side

Table QW -451 is the Procedure qualification thickness limits and test specimens requirements. Each groove weld must pass tension tests and transverse bend tests. This table is where the requirements for testing are listed..

After the procedure qualification testing the Welding Inspector must check production welding to ensure welds are being made in compliance with the approved and tested weld procedure. Remember the weld procedure is proof that the weld can be successfully made.

The general sequence for procedure qualification testing is as follows:

- Select welding variables (write the WPS and PQR)
- Check equipment and materials for suitability
- Monitor weld joint fit-up as well as actual welding, recording all important variables and observations
- Select, identify and remove required test specimens
- Test and evaluate specimens
- Review test results for compliance with applicable code requirements
- Release approved procedure for production
- Qualify individual welders in accordance with this procedure
- Monitor production welding for procedure compliance

**QW-482 SUGGESTED FORMAT FOR WELDING PROCEDURE SPECIFICATIONS  
(WPS)  
(See QW-200.1, Section IX, ASME Boiler and Pressure Vessel Code)**

Company Name: \_\_\_\_\_ By: \_\_\_\_\_  
 Welding Procedure Specification No. \_\_\_\_\_ Date: \_\_\_\_\_ Supporting PQR No.(s) \_\_\_\_\_  
 Revision No. \_\_\_\_\_ Date: \_\_\_\_\_  
 Welding Process(es): \_\_\_\_\_ Type(s): \_\_\_\_\_  
 Automatic, Manual, Machine, or Semi-Auto  
 Details

**JOINTS (QW-402)**  
 Joint Design \_\_\_\_\_  
 Backing (Yes) \_\_\_\_\_ (No) \_\_\_\_\_  
 Backing Material (Type) \_\_\_\_\_  
 (Refer to both backing and retainers)

- Metal     Nonfusing Metal  
 Nonmetallic     Other

Sketches, Production Drawings, Weld Symbols or Written Description should show the general arrangement of the parts to be welded. Where applicable, the root spacing and the details of weld groove may be specified.

(At the option of the Mfr., sketches may be attached to illustrate joint design, weld layers and bead sequence, e.g., for notch toughness procedures, for multiple process procedures, etc.)

**\*BASE METALS (QW-403)**  
 P-No. \_\_\_\_\_ Group No. \_\_\_\_\_ to P-No. \_\_\_\_\_ Group No. \_\_\_\_\_  
 OR  
 Specification type and grade \_\_\_\_\_  
 to Specification type and grade \_\_\_\_\_  
 OR  
 Chem. Analysis and Mech. Prop. \_\_\_\_\_  
 to Chem. Analysis and Mech. Prop. \_\_\_\_\_  
 Thickness Range:  
 Base Metal:                      Groove \_\_\_\_\_                      Fillet \_\_\_\_\_  
 Pipe Dia. Range:                      Groove \_\_\_\_\_                      Fillet \_\_\_\_\_  
 Other: \_\_\_\_\_

<b>*FILLER METALS (QW-404)</b>		
Spec. No. (SFA) _____		
AWS No. (Class) _____		
F-No. _____		
A-No. _____		
Size of Filler Metals _____		
Weld Metal		
Thickness Range:		
Groove _____		
Fillet _____		
Electrode-Flux (Class) _____		
Flux Trade Name _____		
Consumable Insert _____		
Other _____		

\*Each base metal-filler metal combination should be recorded individually

## QW-482 (Back)

WPS No. \_\_\_\_\_ Rev. \_\_\_\_\_

<b>POSITIONS (QW-405)</b> Position(s) of Groove _____ Welding Progression: Up _____ Down _____ Position(s) of Fillet _____				<b>POSTWELD HEAT TREATMENT (QW-407)</b> Temperature Range _____ Time Range _____																								
<b>PREHEAT (QW-406)</b>  Preheat Temp. - Min. _____ Interpass Temp. - Max. _____ Preheat Maintenance _____  (Continuous or special heating where applicable should be recorded)				<b>GAS (QW-408)</b> <table style="width: 100%; border-collapse: collapse;"> <thead> <tr> <th style="width: 30%;"></th> <th colspan="3" style="text-align: center;">Percent Composition</th> </tr> <tr> <th></th> <th style="text-align: center;">Gas(es)</th> <th style="text-align: center;">(Mixture)</th> <th style="text-align: center;">Flow Rate</th> </tr> </thead> <tbody> <tr> <td>Shielding</td> <td style="text-align: center;">_____</td> <td style="text-align: center;">_____</td> <td style="text-align: center;">_____</td> </tr> <tr> <td>Trailing</td> <td style="text-align: center;">_____</td> <td style="text-align: center;">_____</td> <td style="text-align: center;">_____</td> </tr> <tr> <td>Backing</td> <td style="text-align: center;">_____</td> <td style="text-align: center;">_____</td> <td style="text-align: center;">_____</td> </tr> </tbody> </table>						Percent Composition				Gas(es)	(Mixture)	Flow Rate	Shielding	_____	_____	_____	Trailing	_____	_____	_____	Backing	_____	_____	_____
	Percent Composition																											
	Gas(es)	(Mixture)	Flow Rate																									
Shielding	_____	_____	_____																									
Trailing	_____	_____	_____																									
Backing	_____	_____	_____																									
<b>ELECTRICAL CHARACTERISTICS (QW-409)</b> Current AC or DC _____ Polarity _____  Amps (Range) _____ Volts (Range) _____  (Amps and volts range should be recorded for each position, and thickness, etc. This information may be listed in a tabular form similar to that shown below.)  Tungsten Electrode Size and Type _____ (Pure Tungsten, 2% Thorated, etc.)  Mode of Metal Transfer for GMAW _____ (Spray arc, short-circuiting arc, etc.)  Electrode Wire feed speed range _____																												
<b>TECHNIQUE (QW-410)</b> String or Weave Bead _____ Orifice or Gas Cup Size _____ Initial and Interpass Cleaning (Brushing, Grinding, etc.) _____  Method of Back Gouging _____ Oscillation _____ Contact Tube to Work Distance _____ Multiple or Single Pass (per side) _____ Multiple or Single Electrodes _____ Travel Speed (Range) _____ Peening _____ Other _____ _____ _____																												
Weld Layer(s)	Process	Filler Metal		Current		Volt Range	Travel Speed Range	Other (e.g., Remarks, Comments, Hot Wire Addition, Technique, Torch Angle, Etc.)																				
		Class	Dia.	Type Polar	Amp Range																							

**QW-483 SUGGESTED FORMAT FOR PROCEDURE QUALIFICATION RECORD  
(PQR)  
(See QW-200.2, Section IX, ASME Boiler and Pressure Vessel Code)  
Record Actual Conditions Used to Weld Test Coupon**

<b>JOINTS (QW-402)</b>  _____ _____ Company Name _____ Procedure Qualification Record No. _____ Date _____ WPS No. _____ Welding Process(es) _____ Types (Manual, Automatic, Semi-Auto.) _____																					
Groove Design of Test Coupon (For combination qualifications, the deposited weld metal thickness will be required for each filler metal or process used.)																					
<b>BASE METALS (QW-403)</b> Material Spec. _____ Type or Grade _____ P. No. _____ to P-No. _____ Thickness of Test Coupon _____ Diameter of Test Coupon _____ Other _____ _____ _____ _____	<b>POST WELD HEAT TREATMENT (QW-407)</b> Temperature _____ Time _____ Other _____ _____ _____																				
<b>FILLER METALS (QW-404)</b> SFA Specification _____ AWS Classification _____ Filler Metal F-No. _____ Weld Metal Analysis A-No. _____ Size of Filler Metal _____ Other _____ _____ Weld Metal Thickness _____	<b>GAS(QW-408)</b> <table style="width:100%; border-collapse: collapse;"> <thead> <tr> <th></th> <th colspan="3" style="text-align: center;">Percent Composition</th> </tr> <tr> <th></th> <th style="text-align: center;">Gas(es)</th> <th style="text-align: center;">(Mixture)</th> <th style="text-align: center;">Flow Rate</th> </tr> </thead> <tbody> <tr> <td>Shielding</td> <td style="text-align: center;">_____</td> <td style="text-align: center;">_____</td> <td style="text-align: center;">_____</td> </tr> <tr> <td>Trailing</td> <td style="text-align: center;">_____</td> <td style="text-align: center;">_____</td> <td style="text-align: center;">_____</td> </tr> <tr> <td>Backing</td> <td style="text-align: center;">_____</td> <td style="text-align: center;">_____</td> <td style="text-align: center;">_____</td> </tr> </tbody> </table>		Percent Composition				Gas(es)	(Mixture)	Flow Rate	Shielding	_____	_____	_____	Trailing	_____	_____	_____	Backing	_____	_____	_____
	Percent Composition																				
	Gas(es)	(Mixture)	Flow Rate																		
Shielding	_____	_____	_____																		
Trailing	_____	_____	_____																		
Backing	_____	_____	_____																		
<b>POSITION (QW-405)</b> Position of Groove _____ Weld Progression (Uphill, Downhill) _____ Other _____ _____ _____	<b>ELECTRICAL CHARACTERISTICS (QW-409)</b> Current _____ Polarity _____ Amps. _____ Volts _____ Tungsten Electrode Size _____ Other _____ _____ _____																				
<b>PREHEAT (QW-406)</b> Preheat Temp. _____ Interpass Temp. _____ Other _____ _____ _____	<b>TECHNIQUE (QW-410)</b> Travel Speed _____ String or Weave Bead _____ Oscillation _____ Multipass or Single Pass (per side) _____ Single or Multiple Electrodes _____ Other _____ _____ _____ _____																				



**QW-483 (Back)**

PQR No. \_\_\_\_\_

**Tensile Test (QW-150)**

Specimen No.	Width	Thickness	Area	Ultimate Total Load lb.	Ultimate Unit Stress psi	Type of Failure & Location

**Guided-Bend Tests (QW-160)**

Type and Figure No.	

**Toughness Tests (QW-170)**

Specimen No.	Notch Location	Notch Type	Test Temp.	Impact Values	Lateral Exp.		Drop Weight	
					% Shear	Mils	Break	No Break

**Fillet-Weld Test (QW-180)**

Result- Satisfactory: Yes \_\_\_\_\_ No \_\_\_\_\_ Penetration into Parent Metal: Yes \_\_\_\_\_ No \_\_\_\_\_  
 Macro - Results \_\_\_\_\_

**Other Tests**

Type of Test \_\_\_\_\_  
 Deposit Analysis \_\_\_\_\_  
 Other \_\_\_\_\_

Welder's Name \_\_\_\_\_ Clock No. \_\_\_\_\_ Stamp No. \_\_\_\_\_  
 Tests conducted by: \_\_\_\_\_ Laboratory Test No. \_\_\_\_\_

We certify that the statements in this record are correct and that the test welds were prepared, welded, and tested in accordance with the requirements of Section IX of the ASME Code.

Manufacturer \_\_\_\_\_

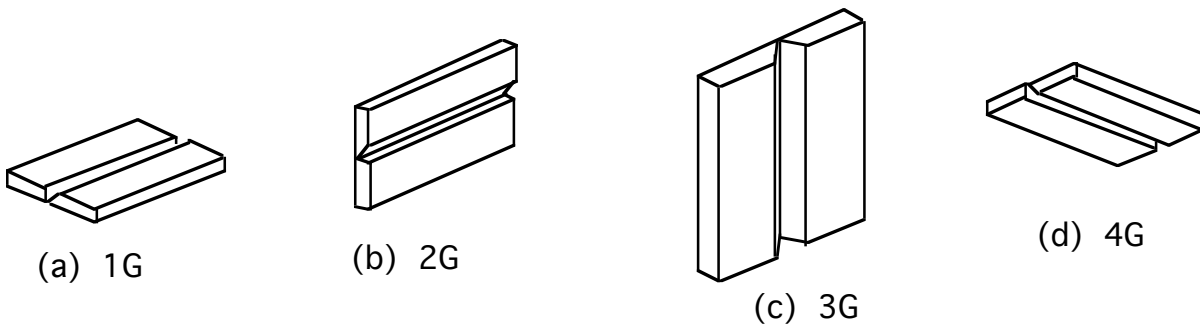
Date \_\_\_\_\_ By \_\_\_\_\_

(Detail of record of tests are illustrative only and may be modified to conform to the type and number of test required by the Code.)

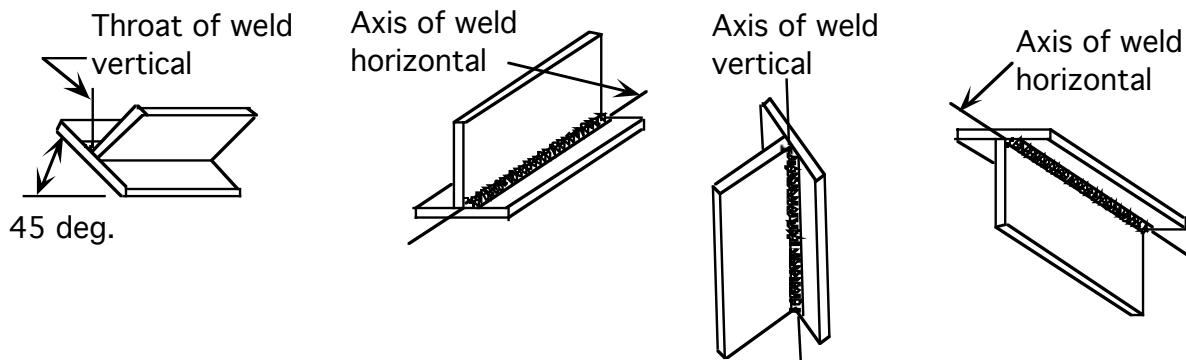
## ASME Section IX Welder Qualification

Welder qualification establishes the skill level for the welder. The test positions are similar to the welding procedure positions. The essential variables for welder qualification are as follows:

- Position
- Joint Configuration
- Electrode Type and Size
- Process
- Base Metal Type
- Base Metal Thickness
- Technique (Up-hill or Down-hill)



QW-461.3 Groove Welds in Plate -- Test Positions



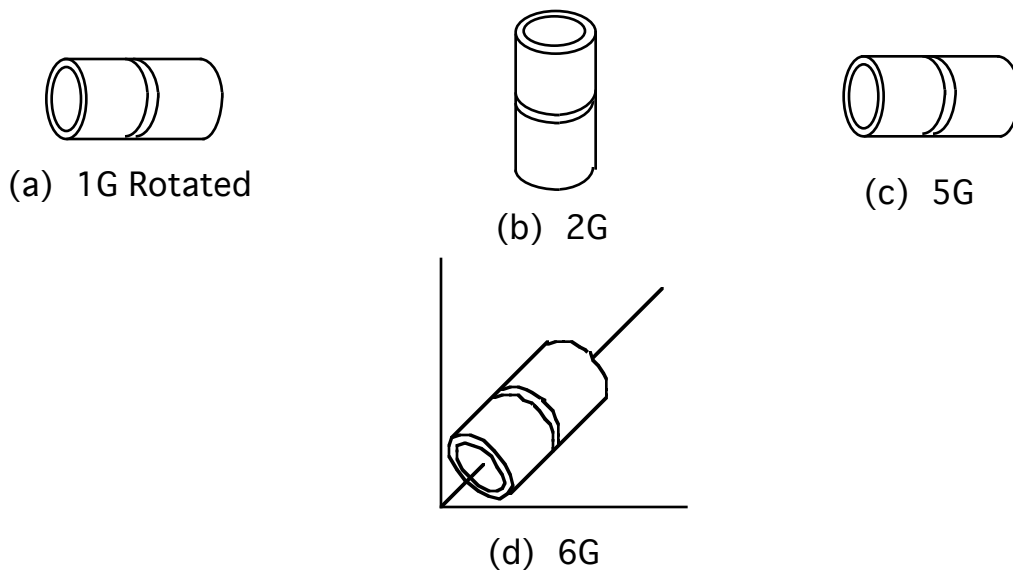
QW-461.5 Fillet Welds in Plate - Test Positions

(a) 1F

(b) 2F

(c) 3F

(d) 4F



QW-461.4 Groove Welds in Pipe -- Test Positions

**PERFORMANCE QUALIFICATION - POSITION AND DIAMETER LIMITATIONS  
(Within the Other Limitations of QW-303)**

Qualification Test		Position and Type Weld Qualified [Note (1)]		
		Groove		Fillet
Weld	Position	Plate and Pipe Over 24 in. O.D.	Pipe ≤ 24 in. O.D.	Plate and Pipe
Plate - Groove	1G	F	F [Note (2)]	F
	2G	F,H	F,H [Note (2)]	F,H
	3G	F,V	F [Note (2)]	F,H,V
	4G	F,O	F [Note (2)]	F,H,O
	3G and 4G	F,V,O	F [Note (2)]	All
	2G, 3G and 4G	All	F,H [Note (2)]	All
	Special Positions m(SP)	SP,F	SP,F	SP,F
Plate - Fillet	1F	...	...	F [Note (2)]
	2F	...	...	F,H [Note (2)]
	3F	...	...	F,H,V [Note (2)]
	4F	...	...	F,H,O [Note (2)]
	3F and 4F	...	...	All [Note (2)]
	Special Positions (SP)	...	...	SP, F [Note (2)]

**PERFORMANCE QUALIFICATION - POSITION AND DIAMETER  
LIMITATIONS  
(Within the Other Limitations of QW-303)**

Position and Type Weld Qualified [Note (1)]

Qualification Test		Position and Type Weld Qualified [Note (1)]		
		Groove		Fillet
Weld	Position	Plate and Pipe Over 24 in. O.D.	Pipe ≤ 24 in. O.D.	Plate and Pipe
Pipe - Groove [Note (3)]	1G	F	F	F
	2G	F,H	F,H	F,H
	5G	F,V,O	F,V,O	All
	6G	All	All	All
	2G and 5G	All	All	All
	Special Positions (SP)	SP,F	SP,F	SP,F
Pipe - Fillet [Note (3)]	1F	...	...	F
	2F	...	...	F,H
	2FR	...	...	F,H
	4F	...	...	F,H,O
	5F	...	...	All
	Special Positions (SP)	...	...	SP,F

NOTES:

- (1) Positions of welding as shown in QW-461.1 and QW-461.2.  
F = Flat  
H = Horizontal  
V = Vertical  
O = Overhead
- (2) Pipe 2 7/8 in. O.D. and over.
- (3) See diameter restrictions in QW-452.3, QW-452.4 and QW-452.6

The general sequence for Welder qualification testing is as follows:

- Identify essential variables
- Check equipment and materials for suitability
- Check test coupon configuration and position
- Monitor actual welding, to assure that it complies with applicable welding procedure
- Select, identify and remove required test specimens
- Test and evaluate specimens
- Complete necessary paperwork
- Monitor production welding

**QW-484 SUGGESTED FORMAT FOR MANUFACTURER'S RECORD OF WELDER OR  
WELDING OPERATOR QUALIFICATION TESTS (WPQ)  
See QW-301, Section IX, ASME Boiler and Pressure Vessel Code**

Welder's name \_\_\_\_\_ Clock no. \_\_\_\_\_ Stamp no. \_\_\_\_\_  
 Welding process(es) used \_\_\_\_\_ Type \_\_\_\_\_  
 Identification of WPS followed by welder during welding of test coupon \_\_\_\_\_  
 Base material(s) welded \_\_\_\_\_ Thickness \_\_\_\_\_

Manual or Semiautomatic Variables for Each Process (QW-350)	Actual Values	Range Qualified
Backing (metal, weld metal, welded from both sides, flux, etc.) (QW-402)	_____	_____
ASME P-No. _____ to ASME P-No. (QW-403)	_____	_____
( ) Plate ( ) Pipe (enter diameter, if pipe)	_____	_____
Filler metal specification (SFA): _____ Classification (QW-404)	_____	_____
Filler metal F-No.	_____	_____
Consumable insert for GTAW or PAW	_____	_____
Weld deposit thickness for each welding process	_____	_____
Welding position (1G, 5G, etc.) (QW-405)	_____	_____
Progression (uphill/downhill)	_____	_____
Backing gas for GTAW, PAW or GMAW, fuel gas for OFW (QW-408)	_____	_____
GMAW transfer mode (QW-409)	_____	_____
GTAW welding current type/polarity	_____	_____

Machine Welding Variables for the Process Used (QW-360)	Actual Values	Range Qualified
Direct/remote visual control	_____	_____
Automatic voltage control (GTAW)	_____	_____
Automatic joint tracking	_____	_____
Welding position (1G, 5G, etc.)	_____	_____
Consumable insert	_____	_____
Backing (metal, weld metal, welded from back sides, flux, etc.)	_____	_____

**Guided-Bend Test Results**

Guided-Bend Tests Type ( )QW-462.2(Side) Results	( )QW-462.3(a) (Trans. R &F) Type	( )QW-462.3(b) (Long R & F) Results

Visual examination results (QW-302.4) \_\_\_\_\_  
 Radiographic test results (QW-304 and QW-305) \_\_\_\_\_  
 (For alternative qualification of groove welds by radiography)  
 Fillet Weld - Fracture test \_\_\_\_\_ Length and percent of defects \_\_\_\_\_ in.  
 Macro test fusion \_\_\_\_\_ Fillet leg size \_\_\_ in. x \_\_\_\_\_ in. Concavity/convexity \_\_\_\_\_ in.  
 Welding test conducted by \_\_\_\_\_  
 Mechanical tests conducted by \_\_\_\_\_ Laboratory test no. \_\_\_\_\_

We certify that the statements in this record are correct and that the test coupons were prepared, welded and tested in accordance with the requirements of Section IX of the ASME Code.

Organization \_\_\_\_\_

Date \_\_\_\_\_

By \_\_\_\_\_



## **Section 10**

### **Welding Metallurgy**

## WELDING METALLURGY

**Admixture:** The interchange of filler metal and base metal during welding, resulting in weld metal of composition borrowed from both. Limited admixture is necessary to complete metallurgical union across the joint.

**Aging:** The recrystallization that occurs over an extended period of time, resulting from austenite or other normally elevated-temperature structure being retained at a temperature and under conditions where it has no permanent stability. The result may be a change in properties or dimension. Under some circumstances, aging can be advantageous.

**Blowhole:** A defect in metal caused by hot metal cooling too rapidly when excessive gaseous content is present. Specifically, in welding, a gas pocket in the weld metal, resulting from the hot metal solidifying without all of the gases having escaped to the surface.

**Crater cracks:** Cracks across the weld bead crater, resulting from hot shrinkage.

**Heat-affected zone:** The portion of the base metal, adjacent to a weld, the structure or properties of which have been altered by the heat of welding.

**Hot shrinkage:** A condition where the thin weld crater cools rapidly while the remainder of the bead cools more slowly. Since metal contracts or shrinks as it cools, and shrinkage in the crater area is restrained by the larger bead, the weld metal at the crater is stressed excessively and may crack.

**Lamination:** An elongated defect in a finished metal product, resulting from the rolling of a welded or other part containing a blowhole. Actually, the blowhole is stretched out in the direction of rolling.

**Pick-up:** The absorption of base metal by the weld metal as the result of admixture. Usually used specifically in reference to the migration of carbon or other critical alloying elements from the base metal into the weld metal. Depending upon the materials involved, this can be an asset and not a liability.

**Segregation:** The tendency of alloying elements, under certain heat conditions, to separate from the main crystalline constituent during transformation and to migrate and collect at the grain boundaries. There they often combine into undesirable compounds.

**Stringers:** The tendency of segregated atoms of alloying elements or their compounds to attach to one another in thread-like chains.

The problems encountered in welding can be better understood through a basic understanding of metallurgy. The metallurgical effects of welding are the effects of heat. Whether the welds are made by a gas flame, a metal arc, or electrical resistance, the effects on the parent metal are due to heat.

Every fusion welding operation involves a logical sequence of thermal or heat events. These include:

1. Heating of the metal
2. Manipulation of the electrode or torch flame to deposit weld metal
3. Cooling of the weld deposit as well as the base metal
4. Reheating of the entire structure for stress-relieving purposes, in some instances

In every weld, the metal immediately under the flame or arc is in a molten state; the welded section is in the process of cooling off; and the section to be welded has not yet been heated and so is comparatively cool. These various conditions are encountered at the very same instant. See Figure M-1.

As a result of welding, the structure of the welded ferrous metal may become martensitic, pearlitic or even austenitic in nature. The welder who knows metallurgy can predict which structure will be found when the weld has cooled. It is most important to know this because the final condition of the structure after welding is the one that determines the strength, hardness, ductility, resistance to impact, resistance to corrosion and similar mechanical and physical properties of the metal. All these properties may be affected by conditions that exist during the welding operation, so it is well to become acquainted with possible difficulties and see how they may be avoided.

To avoid confusion, this discussion will be confined to steel. The effects of heating and cooling will not necessarily be the same for the non-ferrous metals and alloys. In some cases, a considerable difference in temperature ranges and other characteristics exist.

The arc welding of steel involves very high temperatures. The resultant weld is essentially cast steel. Since the base metal very close to the weld is comparatively cool, a considerable variation in the grain structure develops within the weld area. The iron-carbon diagram, Figure M-2 shows how the rate at which the weld cools will alter the grain structure in both the weld itself and the immediately adjacent base metal, known technically as the *heat -affected zone*.

### **Danger from the Air**

Unless extreme care to shield the weld metal is exercised during welding, the possibility exists that oxygen or nitrogen or both will be absorbed from the air. What either of these gases can do to weld metal is pitiful. An oxide or nitride coating will form along the grain boundaries. Oxidation along the grain boundaries greatly weakens the weld metal, and greatly reduces the impact strength and also the fatigue resistance of the welded part. Nitrogen forms iron nitrides in chemical composition with the iron, and these make the weld extremely brittle.



The extent to which oxides and nitrides penetrate a steel will depend upon the type of steel, the temperature to which it is heated and the length of time it is held at this temperature. Extreme care should be exercised to prevent the penetration of air into high-temperature welding regions. The most satisfactory way to prevent oxide or nitride contamination in metal-arc welding is to make sure that the electrode has a coating that provides adequate shielding. The arc and weld metal may also be shielded by carbon dioxide (CO<sub>2</sub>) or vapor. In gas tungsten arc welding (GTAW) or gas metal arc welding (GMAW) (inert-gas-arc welding), the inert gas will provide the shielding. With submerged-arc welding, the molten flux that covers the arc does the job. Fluxes or a reducing flame provide the needed protection during gas welding.

When the oxyacetylene torch is used for cutting, it is desirable to oxidize the steel. It is rapid oxidation that makes it possible for the flame to sever steel.

Besides oxygen or nitrogen, another gas absorbed during welding may have harmful effects on some types of metals and alloys. This gas is hydrogen, and usually comes from moisture in the electrode coating or from the use of hydrogen in the welding flame. The presence of hydrogen in the weld metal will weaken the structure and lead to cracking of the weld. Hydrogen is a contributing cause of underbead cracking. To avoid this harmful weld defect, use low-hydrogen electrodes of the E-xx15, E-xx16 and E-xx18 series.

### **Heat-Affected Zone**

Figure M-2 shows the close relationship that exists between thermal conditions, grain structure and hardness in the arc weld. So that this relationship might be clearly established, a photomicrograph of a section through a welded 0.25% carbon steel plate has been inserted in an iron-carbon diagram. This diagram was split on the 0.25% carbon line and opened up to allow insertion of the photomicrograph.

The photomicrograph is of a single automatic weld bead. The bead as deposited on the 1/2 inch plate produced a heat-affected zone that extended for about 1/8 in. adjacent to the weld. This zone shows a variation in grain structure adjacent to the weld. This zone shows a variation in grain structure (starting at the bottom) from the normal base metal structure into a band of finer grain structure between the lower and upper critical temperature points and then to a coarse overheated grain structure adjacent to the weld.

The extent of the change in the grain structure depends upon the maximum temperature to which the metal is subjected, the length of time this temperature exists, the composition of the steel, and the rate of cooling. The cooling rate will not only affect grain size but it will also affect physical properties.

As a rule, faster cooling rates produce a slightly harder, less ductile and stronger steel. For low-carbon steels, the relatively small differences found in practice make insignificant changes in these values. However, with higher carbon content in appreciable amounts of alloying material, the effect may become serious.

The speed of welding and the rate of heat input into the joint effects change in structure and hardness. On a given mass of base metal, at a given temperature, a small bead deposited at high speed produces a greater hardening than a larger bead deposited at a higher heat input per unit length of joint. This is because small high speed beads cool more rapidly than the larger high heat beads.

The effect that heat from welding has on the base metal determines to a great degree the weldability of a metal and its usefulness in fabrication. A metal that is sensitive to heat conditions or heat changes, as in the case of high-carbon and some alloy steels, may require heat treatment both before and after welding.

### **Admixture or Pick-up**

When a base metal is welded with a filler metal of different composition, the two metals will naturally mix and blend together in the molten weld pool. Consequently, the weld metal will be a mixture of two materials. It will not necessarily be an average of them, however.

The amount of base metal picked up in the molten weld pool varies greatly relative to the amount of deposited electrode metal. Some welds are made up principally of base metal, while others are primarily deposited electrode metal. The specific process of welding, the rate of electrode travel, the current selected, the width of the joint, the base metal composition, the plate thickness -- all these factors determine the volume of base metal brought to a molten temperature, and therefore the amount of base metal *pick-up* or *admixture* into the weld.

In some cases, the deposited metal and the base metal are sufficiently alike in composition that the amount of admixture is of little significance. At other times, admixture is an advantage in that the weld metal is made stronger or otherwise improved by a pick-up of carbon or other needed elements from the base metal.

Unfortunately, under some conditions alloying elements or chemical combinations of the base metal tend to concentrate -- to precipitate, or to *segregate* during the heating and cooling cycle and reform into *stringers* or other arrangements that harden, embrittle, weaken or otherwise cause inferior welds. Sometimes, the stringer itself is a source of weakness. At other times, the segregation of an element or its loss into the slag or atmosphere "starves" the newly formed weld microstructure of elements needed for certain physical properties.

In general, admixture should be limited unless the metals and the processes involved justify a procedure that calls for a specific amount of pick-up. This is discussed further in later chapters on the welding of specific metal groups. To minimize the effects of pick-up, electrode coatings or fluxes are often treated with alloying elements that bring the deposited metal up to the desired composition. These alloying elements replace those that might be destroyed or lost to either parent metal or weld metal during the high-temperature welding operation.

## Carbide Precipitation

Sometimes, because of rapid cooling, steels, particularly stainless steels, are not given time to go through all of the temperature changes indicated in the iron-carbon diagram. As a result, a concentration of the solid solution (austenite) is retained at a temperature where it simply has no business existing. This being against nature, so to speak, the dissolved elements will eventually recrystallize. This type of recrystallization is known as aging. Suppose, however, the metal is reheated before recrystallization can occur. In this event, the carbon will crystallize out of the austenite as iron carbide. This phenomena is known as carbide precipitation.

Stainless steels of the nickel-chromium variety are austenitic in nature even at room temperatures. When such steels are heated, as by welding operations, carbide precipitation is apt to occur. The carbides, or carbon compounds, are chromium as well as iron. When chromium is used up in this way, in chemical union with the precipitated carbon, the remaining austenite is deficient in the chromium element. The result is a serious reduction in the corrosion-resisting properties of the stainless steel.

When the carbides are precipitated in stainless steel, they appear mainly at the grain boundaries. If subjected to corrosion, the carbides along the grain boundaries will be attacked readily. Severe corrosive conditions will cause the grains to lose their coherence and the steel to fail.

In making a weld on stainless, there will always be a region some distance back from the weld where the base metal will be at the exact temperature of the precipitation range: 800-1500°F. Consequently, the stainless qualities of the structure will be lost unless steps are taken to prevent precipitation.

Austenitic stainless steels may be stabilized against carbide precipitation by the addition of elements known as stabilizers. Such elements are columbium and titanium. These elements have a ready affinity for carbon; they will grab and hold fast the carbon that might otherwise have been attracted to the chromium. Moreover, both titanium and columbium carbide resemble stainless steel in having high resistance to corrosion. Stabilized stainless steels, therefore, will not fail under the combination of heat and corrosive attack. Austenitic stainless steels also are available in several grades with extra low carbon (ELC). Since there is less carbon, the possibility of chromium migration to the grain boundaries is minimized.

It is well to remember that the stabilized and ELC austenitic steels will resist carbide precipitation. If the welded stainless is to be subjected to corrosive conditions, particularly at elevated temperatures, the base metal should be a stabilized steel and it should be welded with electrodes or filler rods that have also been stabilized.

## Crater Cracks

In some instances, both arc welds and gas welds develop crater cracks. These come from *hot shrinkage*. The crater cools rapidly while the remainder of the bead is cooling slowly. Since the crater solidifies from all sides toward the center, the conditions are favorable to shrinkage cracks. Such *crater cracks* may lead to failures under stress -- brittle failures since there is an inclination towards fracture without deformation. The remedy is to manipulate the electrode to fill up the craters when you are welding.

## Blowholes, Gas Pockets and Inclusions

Other common welding defects known as blowholes, gas pockets and inclusions involve problems of electrode manipulation rather than metallurgy. These difficulties are created because of the welder's failure to retain the molten weld pool for sufficient time to float entrapped gas, slag and other forms of material.

A *blowhole* or gas pocket represents a bubble of gas in the liquid weld metal. A gas pocket is one that did not reach the surface before the metal began to freeze. Consequently, the gas remains entrapped in the solidified metal.

Some gases, particularly hydrogen, are absorbed by the molten metal and are then given off as the metal begins to cool. If the metal is in a molten condition, the gas bubbles make their way to the surface and disappear. If the bubbles are trapped in the growing grains of solid metal, blowholes are the result.

Blowholes are particularly prevalent in steels high in sulphur. In this case the entrapped gas is either sulphur dioxide or hydrogen sulphide, the hydrogen being supplied from moisture, the fuel gas (in gas welding), the electrode coating or the hydrogen atmosphere that surrounds the weld in atomic-hydrogen welding.

Blowholes may be minimized in the weld area by using a continuous welding technique so that the weld metal will solidify continuously. Most welding operators, through practice, learn to develop welding techniques that will produce a relatively gas-free weld. One of the secrets of such a technique is to keep the molten weld pool at the temperature necessary for the rapid release of absorbed gases. At the same time an unbroken protective atmosphere must be provided over the pool. Modern electrode coatings aid in this problem, for they contain scavenging elements that cleanse the weld pool while it is in molten condition.

Inclusions of slag and other foreign particles in the weld present a type of problem similar to gas pockets and blowholes. These inclusions tend to weaken the weld. Slag is frequently entrapped because of the operator's failure to manipulate torch, filler rod or electrode so as to maintain a molten condition long enough to float out all the foreign material. Ordinarily, the liquid slag freezes and forms a protective coating for the weld deposit. On some occasions, however, because of the force of the flame or arc, it is blown into the molten weld pool. The pool freezes before the slag particle or particles can float to the top, thus producing a defective weld.

Slag inclusions are more common in welds made in the overhead position. The lower density of the slag tends to keep it afloat on the weld pool. In overhead welding, the weld pool first forms at the narrow part of the vee, which is uppermost in the weld. Since the pool tends to drip if kept molten too long, the welder works to have it solidify as rapidly as possible. As a result, inclusions are frequent. This problem in overhead welding can be overcome by using gaseous, non-slagging types of electrodes.

Faulty plate preparation contributes to slag inclusions. If edges of V-joints are beveled at too steep an angle and the gap between plates is too small, the weld metal bridges the gap and leaves a pocket at the root in which slag tends to collect. If back of joint is accessible, slag can be removed by back gouging; however, if this operation is omitted, the result is a defective weld. With a J-joint or U-joint, improper arc manipulation may burn back the inside corners and form pockets that can entrap slag or gases.

In repair of a broken surface, a groove along the break line should be burned out or ground so as to provide clean surfaces properly angled and spaced. Failure to do so may leave an overhang of base metal or an unfilled crack that can entrap slag or gases.

Surfaces to be welded should be thoroughly cleaned of scale, dirt, paint, lubricants, and other chemicals that might contribute to formation of gas or dirt inclusions in the weld.

Welds that contain blowholes, gas pockets and inclusions may develop other defects upon hot work. By the action of hot working, the basic defects are exaggerated to form larger defects. For example, if a piece of weld metal containing a blowhole is rolled, the tendency is to flatten and elongate the hole. This develops a long fibrous defect running in the same direction as the piece that is rolled. Such a condition, known as a *lamination*, will reduce the strength of the metal, particularly in directions at right angles to the lamination.



## **Section 11**

### **Technical Report Writing**

## TECHNICAL REPORT WRITING

### LEGAL IMPLICATIONS

#### I. Preamble Comments

- A. The completeness, factual data transmitted and final validity of **any** equipment inspection depends on the depth and scope of the officially submitted **Inspection Report**.
- B. The customer's perception of **You** as a qualified professional is always strongly influenced by what is contained in the report. Remember the "**Image**" comments earlier? Your report may well be "**the make or break**" factor about whether you or your company will be favorably considered for future inspection activities.
- C. An unknown factor usually exists relative to the "likes, dislikes and preferences" of the person who receives or acts on your inspection report. Some factors include:
  - 1. Organization of data
  - 2. Length of report
  - 3. Factual versus theoretical
  - 4. Precise details or general statement.
  - 5. Recommendations or suggestion.
  - 6. Line-item coverage or report by exceptio.
- D. When developing the Inspection Report, consider:
  - 1. Who will read and/or react to its contents, such as project engineers, superintendents, managers, supervisors, foremen, craftsmen, etc.?
  - 2. Can the report be understood, or will a translator be needed?
  - 3. If repair recommendations or sketches are submitted, how much "hand-holding" is required for them to be understood?

#### II. Date and Signature

For a report to be auditable (legitimate by law), it **must** be dated and signed by the inspector/person involved. Basically, any item worth reporting is worthy of legal validation.

#### III. Report Format/Descriptive Contents

- A. Many of those reading/ reacting to your report simply do not have time to attempt to grasp or correlate those items most useful to their response. Therefore, the report should be factual, concise and reasonably easy to grasp or understand.
- B. An "attention getter", up front statement is always helpful. Simple statement examples could be one of the following or some reasonably similar comment:
1. Based on my inspection survey of Tank \_\_\_\_\_ on \_\_\_\_\_, this equipment is considered to be in good condition and structurally sound for long term service.
- or**
2. My findings/evaluation of this equipment indicates that minor, general internal corrosion of the bottom is occurring, but is of no near term concern. The remainder of this equipment is considered to be in good condition with no corrosion noted.
- or**
3. The inspection survey indicates that moderate to sever internal corrosion exists. Component part thickness measurements, plus visual observations reflect the following conditions and recommendations:

**NOTE:** Remember that the person to whom you submit a report is a **Client**. It may be an "in-house" client for those inspecting equipment owned by their respective employer, or it may be a contract-owner relationship.

- C. Many, if not most, clients will not appreciate, nor perhaps even tolerate, a report that contains "inflammatory" comments. In this context, inflammatory words, comments, opinions or predictions could be anything that, in the event of some future legal action, would place the equipment owner in a precarious, defensive position. Some examples are:
1. Dangerous
  2. Explosion
  3. Hazardous
  4. Health Problem
  5. Unsafe

A simpler explanation would be any comment or wording that could be twisted or used out of context by lawyers in a negligence trial situation.



Certainly, the comments listed above are not meant or intended to cause an inspector to prostitute himself or his profession by "soft-pedaling" or ignoring serious problems, plus informing the client whenever problems exist. Each client deserves a true, factual evaluation and condition report. It is possible, however, to structure your report comments in such a fashion that problems can be stated (or client informed) so as to impart various degrees of urgency or concern involving areas or component items requiring immediate or near term corrective action.

#### IV. **Report Vocabulary**

A. Each individual most probably has already established, or will establish, his own vocabulary (or word usage) to identify or project his evaluation of conditions noted during the inspection survey. Degrees of corrosion/deterioration exist, plus varying stages or phases of problems involving mechanical equipment, safety, environment, etc., must be described and/or commented upon. Some common descriptive phrases/comments I have become comfortable with are listed below. You will note that it is possible to make many combination statements by grouping certain descriptive words into comments that best describe your personal evaluation.

1. Very minor, general corrosion.
2. Minor to moderate, etc., etc.
3. Moderate, etc., etc.
4. Moderate to severe, etc., etc.
5. Severe, etc., etc.
6. The results of this inspection survey indicate that repair as follows is recommended.
7. Inspection/evaluation of this equipment indicates it to be in good condition and is considered OK for long term service.

B. Owner/client user **Expectations**

You are hired (or used) to determine existing conditions of equipment, assess and evaluate the impact on future reliability, determine corrosion/metal thickness limitations or minimum requirements.

You are expected to use your best judgment, expertise, experience and training to develop (perhaps even to recommend), the most **cost effective**, safest, operationally reliable method/degree of repair necessary to achieve the above conditions.

#### V. **Report Structure**

A. Recall earlier comments regarding those who will receive your report plus those who will eventually react to your comments and/or recommendations.

- B. Methods, data organization, component part separation, etc., suggested for your strong consideration include:
1. Method of presentation
    - a. Keep the report as brief( but complete) as possible or practical.
    - b. Keep it factual. If theorizing is required, make sure that this approach is recognized.
    - c. Avoid, whenever possible, inflammatory words or comments.
    - d. Be conscious of the economics involved. Don't recommend complete item renewal, when 50% renewal will provide the desired results.
  2. Data Organization / Component Part Separation

In reporting conditions found, **separate** into component tank parts (i.e., shell, bottom, fixed roof, I.F.R., etc.)

**NOTE:** **Do not** intermingle comments/ conditions, so that a thought pattern is established in the report readers mind on one component of the tank (i.e., shell) and then refer to the bottom in mid-stream. Keep comments separated in the report body **and on the repair items recommended.**

Ideally, repair items should be arranged in order, clearly defined and explicit enough, that the list can be given to maintenance personnel who can make proper repairs from the list.

## VI. Review Comments

The following are "**Basic**" in nature, but occasionally can be flexible to fit the needs of a particular situation:

- A. Do's
1. Keep as brief as possible, but present all factual data. A wide flexibility is necessary because of the range of comments required to satisfy numerous conditions.
  2. Provide suggestions or recommendations relative to repair if the client requests. Sketches involving repair or procedure details are a mark of competence.
  3. Be conscious of the economics involved that could result from your recommendations.
  4. Arrange data in an orderly fashion, separated into component parts for ease of reading and understanding.
  5. Sign and date report.

B. Don'ts

1. Use inflammatory word, statements or opinions.
2. Present a mass of data all intermingled in one statement.
3. Make it a practice to theorize or guess as to problem cause.
4. Present condition comments or data involving one major tank component into the same statement as data is presented on a completely different major component.
5. Diminish your competency or professional image by a failure to submit a comprehensive, factual, readable report that will, by itself, be a future auditable document.