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Facilities Maintenance Guide

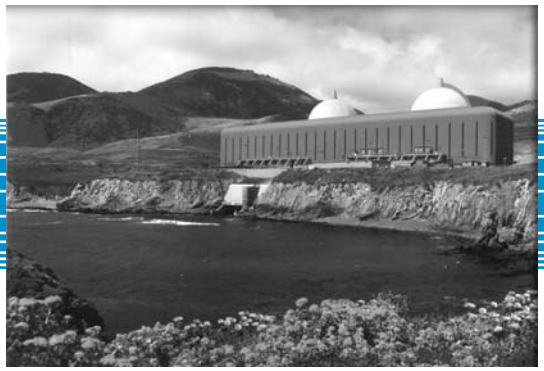
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Technical Report





NMAC

Facilities Maintenance Guide

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Final Report, July 2004

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REPORT SUMMARY

The subject of facilities maintenance is very broad and is commonly interpreted quite differently among maintenance managers at power plants and U.S. Department of Energy (DOE) nuclear and process facilities. In many cases, the maintenance of administrative buildings, support structures, and "real property" is managed separately from the maintenance of process equipment. The scope and breadth of each maintenance program varies from site to site, as does the formality of the program established to address the general maintenance and upkeep of real property. The methods of distinguishing, categorizing, and classifying structures, systems, and components also vary between nuclear power plants and U.S. DOE process facilities. These major issues were taken into consideration in the development of this report, and they formed the basis from which the report's detailed guidance was developed.

Background

Because the ages of many nuclear units and U.S. DOE nuclear and process facilities exceed 40 years, the maintenance costs associated with process, administrative, and support facilities continue to rise. These structures, although not directly related to the generation of nuclear power or the primary mission of a U.S. DOE process facility, are important in supporting the operation of each facility. In some cases, maintenance of these facilities and properties has not been planned and implemented to the same degree as those structures directly supporting the generation of electricity. At other facilities, the maintenance has been deferred, has become backlogged, and is difficult to manage effectively.

An extensive search was conducted for industry information relating to facility maintenance planning, aging, and practices. This guide includes descriptive information, design considerations, industry failure and aging data, inspection criteria, maintenance tasks, and replacement issues.

Objectives

- To provide a comprehensive treatment of support, administrative facilities, and property maintenance to personnel at nuclear power plants and U.S. DOE nuclear facilities
- To provide guidance regarding failure mechanisms for various building elements and facility components
- To provide a means for establishing the baseline condition from which to assess the facility or property
- To provide different inspection techniques and information about their effective use
- To provide guidance for performing preventive maintenance and repairs

Approach

In cooperation with interested Nuclear Maintenance Applications Center (NMAC) members, a task group of utility engineers and industry experts was formed. This group identified key maintenance issues regarding support facilities and buildings at nuclear power plants and U.S. DOE process facilities and provided input used in the preparation of the guidance set forth in this document. Experience-proven practices and techniques were identified during this effort and compiled in this report.

Results

This guide provides the user with an understanding of facility components and building elements, including technical descriptions, typical applications, and common materials and construction. The scope of the guide includes common plant applications, failure modes and troubleshooting guidance, condition monitoring and inspection, predictive maintenance techniques, preventive maintenance strategies, and generic repair guidance. The guide also describes the different types of maintenance—including deferred maintenance—and techniques for assessing whether to repair or replace a particular building element.

EPRI Perspective

The information contained in this guide represents a significant collection of technical information—including techniques and good practices—related to the maintenance, monitoring, and troubleshooting of facilities that typically support a nuclear power plant or U.S. DOE process facility. Assemblage of this information provides a single point of reference for plant personnel now and in the future. Through the use of this guide, in close conjunction with the technical guidance provided by each product or building element manufacturer, EPRI members should be able to significantly improve and optimize their existing facilities' predictive, preventive, and corrective maintenance programs related to support structures and buildings on site. This will subsequently help members achieve increased reliability and availability of the facilities (and the process equipment located inside those facilities) at a decreased cost.

Keywords

Facilities maintenance
Inspection
Building element
Preventive maintenance
Deferred maintenance
Condition assessment

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CONTENTS

1 INTRODUCTION 1-1
1.1 Background 1-1
1.2 Purpose 1-1
1.3 Scope 1-2
1.3.1 Scope of Facilities and Facility Components Described in This Report 1-2
1.3.2 Scope and Organization of This Report 1-3
1.4 Integration of Guidance in This Report 1-3
1.5 Effective Use of the Guidance in This Report 1-4
1.6 Acronyms 1-5
1.7 Key Points 1-7
1.8 Unit Conversions 1-9

2 FACILITIES MAINTENANCE OVERVIEW 2-1
2.1 Types of Maintenance 2-1
2.2 Types of Forces Acting on Facilities 2-2
2.3 Scope and Types of Building Elements 2-3
2.3.1 Major Structural Elements 2-3
2.3.1.1 Reinforced Concrete 2-3
2.3.1.2 Structural Steel 2-4
2.3.1.3 Wood/Timber 2-4
2.3.2 Facility Finish Materials 2-5
2.3.2.1 Exterior Materials 2-5
2.3.2.2 Interior Ceiling and Wall Materials 2-5
2.3.2.3 Floors 2-9
2.3.2.4 Roofs 2-12
2.3.2.5 Windows and Doors 2-14
2.3.2.6 Coatings for Exterior Surfaces 2-15

2.3.3 Facility Systems 2-19
2.3.3.1 Water Distribution Systems 2-20
2.3.3.2 Heating, Ventilating, and Air Conditioning Systems 2-20
2.3.3.3 Electrical Systems 2-20
2.3.3.4 Conveying Systems 2-22
2.3.4 External Systems 2-22
2.3.4.1 Walks, Drives, Curbs, and Asphalt Surfaces 2-22
2.3.4.2 Runoff, Drainage, and Erosion Control Systems 2-23
2.3.4.3 Fences 2-24
2.3.4.4 Tanks 2-25
2.4 Advantages and Disadvantages of Various Building Materials 2-25

3 FAILURE MECHANISMS AND AGING MODES 3-1
3.1 Introduction 3-1
3.1.1 Types of Loads 3-1
3.1.2 Stress and Strain 3-1
3.1.3 Tension and Compression 3-2
3.1.4 Types of Stress 3-2
3.2 Failure Mechanisms of Major Structural Materials 3-3
3.2.1 Reinforced Concrete 3-3
3.2.2 Structural Steel 3-6
3.2.3 Wood/Timber 3-7
3.3 Failure Mechanisms of Facility Finish Materials 3-10
3.3.1 Exterior Materials 3-10
3.3.1.1 Wood Exteriors 3-10
3.3.1.2 Metal Exteriors 3-10
3.3.1.3 Masonry and Concrete Exteriors 3-10
3.3.1.4 Mineral-Surfaced Board Exteriors 3-10
3.3.2 Interior Ceiling and Wall Materials 3-10
3.3.3 Floors 3-12
3.3.4 Roofs 3-13
3.3.5 Windows and Doors 3-15
3.3.6 Coatings for Exterior Surfaces 3-16
3.3.6.1 Exterior Deterioration 3-16
3.3.6.2 Disintegration 3-17
3.3.6.3 Complete Deterioration 3-17

3.4 Failure Mechanisms of Facility Systems 3-18
3.4.1 Water Distribution Systems 3-18
3.4.1.1 Fresh and Waste Water Plumbing Systems 3-18
3.4.1.2 Fire Protection Systems 3-20
3.4.2 Heating, Ventilating, and Air Conditioning Systems 3-20
3.4.2.1 Facility and Building Ventilating and Exhaust Air Systems 3-20
3.4.2.2 Building Heating Systems 3-22
3.4.2.3 Pneumatic Systems 3-24
3.4.2.4 Air Conditioning Systems 3-25
3.4.3 Electrical Systems 3-27
3.4.3.1 Electrical Distribution Systems 3-27
3.4.3.2 Lighting Systems 3-28
3.4.3.3 Motors 3-28
3.4.3.4 Batteries 3-29
3.4.3.5 Transformers 3-29
3.4.3.6 Alarm and Public Address Systems 3-29
3.4.4 Conveying Systems 3-29
3.4.4.1 Hydraulic Elevators 3-29
3.4.4.2 Traction Elevators 3-30
3.4.4.3 Escalators 3-30
3.5 Failure Mechanisms of External Systems 3-30
3.5.1 Walks, Drives, Curbs, and Asphalt Surfaces 3-30
3.5.2 Runoff, Drainage, and Erosion Control Systems 3-31
3.5.2.1 Wind Erosion 3-31
3.5.2.2 Water Erosion 3-31
3.5.2.3 Failure Mechanisms of Drainage and Erosion Control Structures 3-31
3.5.3 Fences 3-31
3.5.4 Tanks 3-32
3.6 Troubleshooting Failures 3-32
3.7 Estimating Design Life 3-32

4 CONDITION-BASED MONITORING 4-1
4.1 Introduction 4-1
4.1.1 General Facilities Inspection Guidance 4-1
4.1.2 Recommended Inspection Frequencies 4-2

4.2 Inspection of Major Structural Materials....4-3
4.2.1 Reinforced Concrete....4-3
4.2.1.1 General Inspection Criteria....4-3
4.2.1.2 Inspection Criteria for Slabs on Grade....4-5
4.2.1.3 Inspection Criteria for Cast-in-Place Concrete Beams and Columns....4-6
4.2.1.4 Inspection Criteria for Loaded Precast Concrete Beams and Columns....4-6
4.2.2 Structural Steel....4-7
4.2.2.1 General Inspection Criteria....4-7
4.2.2.2 Inspection Criteria for Steel Beams and Columns....4-8
4.2.2.3 Inspection Criteria for Pre-Engineered Metal Building Systems....4-9
4.2.3 Wood/Timber....4-10
4.2.3.1 General Inspection Criteria....4-10
4.2.3.2 Decay....4-11
4.2.3.3 Marine Borers....4-11
4.2.3.4 Insects....4-11
4.2.3.5 Inspection Criteria for Wood Beams and Columns....4-12
4.2.3.6 Inspection Criteria for Pre-Engineered Wood Building Systems....4-13
4.2.3.7 Inspection Criteria for Column Fireproofing....4-13
4.3 Inspection of Facility Finish Materials....4-14
4.3.1 Exterior Materials....4-14
4.3.1.1 Wood Exteriors....4-14
4.3.1.2 Metal Exteriors....4-14
4.3.1.3 Masonry and Concrete Exteriors....4-15
4.3.1.4 Mineral-Surfaced Board Exteriors....4-15
4.3.2 Interior Ceiling and Wall Materials....4-16
4.3.2.1 General Inspection Criteria....4-16
4.3.2.2 Inspection Criteria for Conventional Partitions....4-16
4.3.2.3 Inspection Criteria for Specialty Partitions....4-17
4.3.2.4 Inspection Criteria for Toilet Partitions....4-17
4.3.2.5 Inspection Criteria for Wall Covering Systems....4-17
4.3.2.6 Inspection Criteria for Ceiling Systems....4-18
4.3.3 Floors and Stairs....4-18
4.3.3.1 Inspection Criteria for Cast-in-Place Concrete Floors....4-19
4.3.3.2 Inspection Criteria for Precast Concrete Floors....4-19
4.3.3.3 Inspection Criteria for Steel Floors....4-20

4.3.3.4 Inspection Criteria for Composite Floors....4-20
4.3.3.5 Inspection Criteria for Wood Floors....4-21
4.3.3.6 Inspection Criteria for Floor-Finishing Systems....4-22
4.3.4 Roofs....4-22
4.3.4.1 General Inspection Criteria....4-22
4.3.4.2 Inspection Criteria for Concrete Roof Structures....4-23
4.3.4.3 Inspection Criteria for Steel Roof Structures....4-23
4.3.4.4 Inspection Criteria for Wood Roof Structures....4-24
4.3.4.5 Inspection Criteria for Built-Up Membrane Roofs....4-25
4.3.4.6 Inspection Criteria for Single-Ply Membrane Roofs....4-25
4.3.4.7 Inspection Criteria for Metal Roofing Systems....4-26
4.3.4.8 Inspection Criteria for Coated Foam-Membrane Roofs....4-26
4.3.4.9 Inspection Criteria for Shingle Roofs....4-27
4.3.4.10 Inspection Criteria for Tile Roofs....4-27
4.3.4.11 Inspection Criteria for Parapets....4-28
4.3.4.12 Inspection Criteria for Roof Drainage Systems....4-28
4.3.4.13 Inspection Criteria for Roof Specialties....4-29
4.3.4.14 Inspection Criteria for Roof Skylights....4-29
4.3.5 Windows and Doors....4-30
4.3.5.1 Inspection Criteria for Windows....4-30
4.3.5.2 Inspection Criteria for Interior Doors....4-31
4.3.6 Coatings for Exterior Surfaces....4-31
4.4 Inspection of Facility Systems....4-32
4.4.1 Water Distribution Systems....4-32
4.4.1.1 Fresh and Waste Water Plumbing Systems....4-32
4.4.1.2 Fire Protection Systems....4-34
4.4.1.3 Toilets, Lavatories, and Accessories....4-35
4.4.1.4 Sewage Ejectors....4-35
4.4.1.5 Storage Tanks....4-36
4.4.1.6 Tanks and Sumps....4-36
4.4.1.7 Water Conditioners....4-37
4.4.2 Heating, Ventilating, and Air Conditioning Systems....4-37
4.4.2.1 Duct and Air Transport Systems....4-37
4.4.2.2 Heating Systems....4-39
4.4.2.3 Water Heaters....4-42

4.4.2.4 Pneumatic Systems 4-43
4.4.2.5 Steam Distribution Systems 4-50
4.4.2.6 High-Temperature Water Distribution Systems 4-51
4.4.2.7 Instruments and Controls 4-52
4.4.2.8 Air Conditioning Systems 4-53
4.4.3 Electrical Systems 4-55
4.4.3.1 Electrical Distribution Systems 4-55
4.4.3.2 Lighting Systems 4-57
4.4.3.3 Motors 4-59
4.4.3.4 Batteries 4-61
4.4.3.5 Transformers 4-62
4.4.3.6 Alarm and Public Address 4-64
4.4.4 Conveying Systems 4-65
4.4.4.1 Hydraulic Elevators 4-65
4.4.4.2 Traction Elevators 4-65
4.4.4.3 Escalators 4-66
4.5 Inspection of External Systems 4-66
4.5.1 Walks, Drives, Curbs, and Asphalt Surfaces 4-66
4.5.2 Runoff, Drainage, and Erosion Control Systems 4-66
4.5.3 Fences 4-66
4.5.4 Tanks 4-67

5 PREVENTIVE AND PREDICTIVE MAINTENANCE 5-1
5.1 Routine Maintenance for Major Structural Materials 5-1
5.1.1 Reinforced Concrete 5-1
5.1.1.1 Prevention of Deterioration 5-1
5.1.1.2 Routine Maintenance 5-2
5.1.1.3 Coatings 5-3
5.1.1.4 Stain Removal 5-4
5.1.2 Structural Steel 5-5
5.1.2.1 Prevention of Deterioration 5-5
5.1.2.2 Routine Maintenance 5-7
5.1.3 Wood/Timber 5-8
5.1.3.1 Arresting Decay of Wood/Timber Elements 5-8
5.1.3.2 Preventing Termite Damage 5-8

5.1.3.3 Treatment for Termites 5-9
5.1.3.4 Preventive Measures Against Checking 5-9
5.1.3.5 Wood Treatments 5-10
5.2 Maintenance of Facility Finish Materials 5-11
5.2.1 Exterior Materials 5-11
5.2.1.1 Wood Exteriors 5-11
5.2.1.2 Metal Exteriors 5-11
5.2.1.3 Masonry and Concrete Exteriors 5-12
5.2.1.4 Mineral-Surfaced Board Exteriors 5-12
5.2.2 Interior Ceiling and Wall Materials 5-14
5.2.2.1 Plaster 5-14
5.2.2.2 Drywall 5-14
5.2.2.3 Ceramic Tile 5-14
5.2.2.4 Acoustical Tile 5-14
5.2.2.5 Wood 5-15
5.2.3 Floors 5-15
5.2.3.1 General Guidance 5-15
5.2.3.2 Types of Routine Floor Maintenance 5-16
5.2.3.3 Detailed Floor Maintenance Procedures 5-16
5.2.4 Roofs 5-19
5.2.4.1 Built-Up Roofs 5-19
5.2.4.2 Asphalt Shingle Roofs 5-19
5.2.4.3 Asphalt Rolled Roofs 5-19
5.2.4.4 Asphalt Cement Roofs 5-20
5.2.4.5 Metal Roofs 5-20
5.2.4.6 Slate Roofs 5-21
5.2.4.7 Wood-Shingle Roofs 5-21
5.2.4.8 Single-Membrane Roofs 5-21
5.2.5 Windows and Doors 5-22
5.2.5.1 Windows 5-22
5.2.5.2 Doors 5-22
5.2.6 Coatings for Exterior Surfaces 5-23
5.3 Routine Maintenance of Facility Systems 5-24
5.3.1 Water Distribution Systems 5-24
5.3.1.1 Fresh and Waste Water Plumbing Systems 5-24

5.3.1.2 Fire Protection Systems 5-26
5.3.2 Heating, Ventilating, and Air Conditioning Systems 5-26
5.3.2.1 Duct and Air Transport Systems 5-27
5.3.2.2 Heating Systems 5-27
5.3.2.3 Water Heaters 5-29
5.3.2.4 Pneumatic Systems 5-30
5.3.2.5 Steam Distribution Systems 5-32
5.3.2.6 High-Temperature Water Distribution Systems 5-32
5.3.2.7 Instruments and Controls 5-32
5.3.2.8 Air Conditioning Systems 5-33
5.3.3 Electrical Systems 5-35
5.3.3.1 Electrical Distribution Systems 5-35
5.3.3.2 Lighting Systems 5-36
5.3.3.3 Motors 5-38
5.3.3.4 Batteries 5-40
5.3.3.5 Transformers 5-41
5.3.3.6 Alarm and Public Address 5-41
5.3.4 Conveying Systems 5-41
5.4 Routine Maintenance of External Systems 5-42
5.4.1 Walks, Drives, Curbs, and Asphalt Surfaces 5-42
5.4.2 Runoff, Drainage, and Erosion Control Systems 5-42
5.4.2.1 Drainage and Erosion Control Systems 5-42
5.4.2.2 Drainage and Erosion Control Structures 5-42
5.4.3 Fences 5-45
5.4.4 Tanks 5-45

6 CORRECTIVE MAINTENANCE AND REPAIRS 6-1
6.1 Repairing Major Structural Materials 6-1
6.1.1 Repairing Reinforced Concrete 6-1
6.1.1.1 Pre-Repair Considerations 6-1
6.1.1.2 Repairing Cracks in Concrete 6-2
6.1.1.3 Repair of Water Seepage 6-4
6.1.1.4 Thermosetting Plastic (Epoxy) 6-4
6.1.1.5 Curing the Repair 6-5
6.1.2 Repairing Structural Steel 6-5

6.1.2.1 Structural Steel Elements 6-5
6.1.2.2 Connections 6-6
6.1.2.3 Specialized Repairs of Structural Elements 6-7
6.1.3 Repairing Wood/Timber Structural Members 6-8
6.1.3.1 General Repair Guidance 6-8
6.1.3.2 Glue-Laminated Members 6-9
6.2 Repair of Facility Finish Materials 6-9
6.2.1 Exterior Materials 6-9
6.2.1.1 Wood Exteriors 6-9
6.2.1.2 Metal Exteriors 6-9
6.2.1.3 Masonry and Concrete Exteriors 6-11
6.2.1.4 Mineral-Surfaced Board Exteriors 6-11
6.2.2 Interior Ceiling and Wall Materials 6-12
6.2.2.1 Plaster 6-12
6.2.2.2 Drywall 6-12
6.2.2.3 Ceramic Tile 6-12
6.2.2.4 Acoustical Tile 6-12
6.2.2.5 Wood 6-12
6.2.3 Floors 6-13
6.2.3.1 Resilient Floors 6-13
6.2.3.2 Masonry Floors 6-13
6.2.3.3 Metal Floors 6-13
6.2.3.4 Seamless Floors 6-13
6.2.3.5 Wood Floors 6-13
6.2.3.6 Carpets 6-14
6.2.4 Roofs 6-14
6.2.4.1 Built-Up Roofs 6-14
6.2.4.2 Asphalt Shingle Roofs 6-16
6.2.4.3 Asphalt Rolled Roofs 6-16
6.2.4.4 Asphalt Cement Roofs 6-16
6.2.4.5 Metal Roofs 6-16
6.2.4.6 Slate Roofs 6-17
6.2.4.7 Wood Shingle Roofs 6-17
6.2.4.8 Single Membrane Roofs 6-17
6.2.5 Windows and Doors 6-17

6.2.6 Coatings for Exterior Surfaces 6-18
6.3 Repair of Facility Systems 6-18
6.3.1 Water Distribution Systems 6-18
6.3.1.1 Fresh and Waste Water Plumbing Systems 6-18
6.3.1.2 Fire Protection Systems 6-18
6.3.2 Heating, Ventilating, and Air Conditioning Systems 6-18
6.3.3 Electrical Systems 6-19
6.3.4 Conveying Systems 6-19
6.4 Repair of External Systems 6-19
6.4.1 Walks, Drives, Curbs, and Asphalt Surfaces 6-19
6.4.2 Runoff, Drainage, and Erosion Control Systems 6-21
6.4.3 Fences 6-21
6.4.3.1 Patching 6-21
6.4.3.2 Replacing Chain-Link Fencing 6-22
6.4.4 Tanks 6-22

7 FACILITIES MAINTENANCE MANAGEMENT 7-1
7.1 Repair, Replacement, and Deferral Analysis 7-1
7.1.1 Factors Considered During Comprehensive Analysis 7-1
7.1.1.1 Quantifiable Factors for Economic Cost Study 7-2
7.1.1.2 Key Qualitative Factors in the Decision-Making Process 7-4
7.1.1.3 Other Qualitative Factors for Consideration 7-4
7.2 Decision-Making Process 7-6
7.2.1 Decision to Repair Deterioration 7-7
7.2.2 Repairing Deterioration 7-8
7.2.2.1 Selecting a Repair Procedure 7-8
7.2.2.2 Additional Repair Considerations 7-9
7.2.3 Deferring a Repair 7-9
7.2.4 Using Contractors and Outsourcing Repairs 7-9
7.2.5 Evaluating the Effectiveness of the Decision 7-10
7.3 Alternative Analysis Methods 7-10
7.4 Other Facilities Maintenance Management Issues 7-11
7.4.1 Long-Term Costs of Facilities 7-11
7.4.2 Accessibility to Design Information and Configuration Management 7-11

8 REFERENCES 8-1
8.1 In-Text References 8-1
8.2 Bibliography 8-1
8.3 Additional Related EPRI Guidelines 8-2
8.4 Industry and Trade Organizations 8-6

A KEY PROGRAMMATIC ELEMENTS A-1
A.1 Facility Identification and Categorization A-1
A.1.1 Functional Type of Categorization A-1
A.1.2 Distinguishing Real Property A-1
A.2 Types and Prioritization of Maintenance Activities A-2
A.2.1 Introduction A-2
A.2.2 Reactive Maintenance A-2
A.2.3 Preventive Maintenance A-2
A.2.4 Predictive Maintenance A-3
A.2.5 Reliability-Centered Maintenance A-4
A.2.6 Deferred Maintenance A-4

B ESTIMATED DESIGN LIFE B-1
B.1 Foundations B-1
B.2 Substructures B-2
B.2.1 Slabs on Grade B-2
B.2.2 Columns B-2
B.3 Superstructures B-2
B.3.1 Floor Slabs and Decks B-2
B.3.2 Stairs B-3
B.3.3 Structural Frame B-3
B.3.4 Interior Structural Walls B-3
B.3.5 Floor Slabs and Decks B-3
B.4 Exterior Closures B-4
B.5 Roofing B-5
B.6 Interior Finishes and Construction B-6
B.6.1 Walls B-6
B.6.2 Railing and Handrails B-7
B.6.3 Walls, Floors, and Ceilings B-7

B.7 Conveying Systems B-8
B.8 Mechanical Systems B-8
B.8.1 Plumbing B-8
B.8.2 Fire Protection Equipment B-9
B.8.3 Heating, Ventilating, and Air Conditioning Equipment B-10
B.9 Mechanical Systems B-12
B.9.1 Service and Distribution B-12
B.9.1.1 Low Voltage B-12
B.9.1.2 Medium Voltage B-13
B.9.2 Lighting B-13
B.9.3 Special Systems B-13
B.10 Specialty Systems B-13
B.11 Site Work B-14
B.11.1 Paving Roadways and Walkways B-14
B.11.2 Tunnels B-14
B.11.3 Security Fences and Gates B-14
B.11.4 Bridges and Abutments B-14

_C_ CODES AND STANDARDS C-1
C.1 Purpose C-1
C.2 Federal Specifications C-2
C.3 National Standards C-8
C.3.1 Air Conditioning and Refrigeration Institute C-8
C.3.2 Air Movement and Control Association C-8
C.3.3 American Architectural Manufacturers Association C-9
C.3.4 American Association of Textile Colorists and Chemists C-9
C.3.5 American Concrete Institute C-9
C.3.6 American Hardboard Association C-10
C.3.7 American Institute of Steel Construction C-10
C.3.8 American Institute of Timber Constructions C-10
C.3.9 American Iron and Steel Institute C-10
C.3.10 American National Standards Institute C-10
C.3.11 American Plywood Association C-11
C.3.12 American Society for Testing and Materials C-11

C.3.13 American Society of Heating, Refrigeration, and Air Conditioning Engineers C-18
C.3.14 American Society of Mechanical Engineers C-19
C.3.15 American Welding Society C-19
C.3.16 American Wood-Preservers' Association C-19
C.3.17 Brick Institute of America C-20
C.3.18 Building Officials and Code Administrators International C-20
C.3.19 Concrete Reinforcing Steel Institute C-20
C.3.20 Door and Hardware Institute C-20
C.3.21 Exterior Insulation Manufacturers Association C-20
C.3.22 Flat Glass Marketing Association C-20
C.3.23 Gypsum Association C-21
C.3.24 Institute of Electrical and Electronic Engineers C-21
C.3.25 National Association of Architectural Metal Manufacturers C-21
C.3.26 National Association of Garage Door Manufacturers C-21
C.3.27 National Association of Plumbing/Heating/Cooling Contractors C-21
C.3.28 National Fire Protection Association C-21
C.3.29 National Forest Products Association C-23
C.3.30 National Hardwood Lumber Association C-23
C.3.31 National Oak Flooring Manufacturers Association C-23
C.3.32 National Terrazzo and Mosaic Association, Inc. C-23
C.3.33 National Wood Windows and Door Association C-23
C.3.34 Plumbing and Drainage Institute C-23
C.3.35 Portland Cement Association C-23
C.3.36 Precast/Prestressed Concrete Institute C-23
C.3.37 Sheet Metal and Air Conditioning Contractors Association C-24
C.3.38 Society for Protective Coatings C-24
C.3.39 Steel Door Institute C-24
C.3.40 Truss Plate Institute C-24
C.3.41 Underwriters Laboratories, Inc. C-24
C.3.42 Uniform Building Code C-25
C.4 Industry Publications C-25

_D_ LISTING OF KEY INFORMATION D-1

D.1 Key O&M Cost Points D-1

D.2 Key Technical Points D-1

D.3 Key Human Performance Points D-2

_E_ TRANSLATED TABLE OF CONTENTS E-1

Français (French) E-2

日本語（Japanese) E-20

Español (Spanish) E-39

LIST OF FIGURES

Figure 1-1 Integration of Maintenance Guidance....1-4
Figure 2-1 Characteristics and Product Information of Paint Material/Coatings 2-17
Figure 4-1 Advantages and Benefits of Visual Inspections for Coatings Condition Assessment....4-32
Figure 7-1 Factors Considered During the Decision-Making Process 7-2
Figure 7-2 Process for Managing Facilities Maintenance Decisions....7-7
Figure 7-3 Long-Term Costs of Facilities....7-11

LIST OF TABLES

Table 1-1 Scope of Structures, Systems, and Components 1-2
Table 1-2 Conversion Factors 1-9
Table 2-1 Summary of Forces 2-2
Table 2-2 Interior Finishes: Wall Materials 2-7
Table 2-3 Interior Finishes: Wall Coverings 2-8
Table 2-4 Types of Flooring Materials and Their Relative Characteristics 2-9
Table 2-5 Available Roofing and Roofing Sandwich Components 2-14
Table 2-6 Paints Available for Typical Exterior Building Exposure 2-18
Table 2-7 Advantages and Disadvantages of Major Building Materials 2-25
Table 3-1 Summary of Major Structural Material Failure Mechanisms 3-3
Table 3-2 Failure Mechanisms for Reinforced Concrete 3-4
Table 3-3 Failure Mechanisms for Structural Steel 3-6
Table 3-4 Failure Mechanisms for Wood/Timber Members 3-7
Table 3-5 Common Imperfections in Wood/Timber 3-8
Table 3-6 Decay Resistance of Major Woods 3-9
Table 3-7 Common Failure Mechanisms and Symptoms for Various Interior Building Materials 3-12
Table 3-8 Common Failure Mechanisms for Flooring Materials 3-13
Table 3-9 Failure Mechanisms for Various Types of Roofs 3-14
Table 3-10 Typical Pump Failure Mechanisms 3-19
Table 3-11 Ventilating and Exhaust Air System Failure Mechanisms 3-21
Table 3-12 Building Heating Systems Failure Mechanisms 3-22
Table 3-13 Pneumatic Systems Failure Mechanisms 3-24
Table 3-14 Air Conditioning Systems Failure Mechanisms 3-25
Table 3-15 Failure Mechanisms of Components in Electrical Distribution Systems 3-27
Table 3-16 Failure Mechanisms of Lighting Equipment and Their Causes 3-28
Table 3-17 Asphalt Failure Mechanisms and Symptoms of Deterioration 3-30
Table 4-1 Recommended Inspection Frequencies 4-2
Table 4-2 Survey of Existing Concrete 4-3
Table 4-3 Inspection Criteria for Structural Steel 4-8
Table 4-4 Inspection Criteria for Wood/Timber Building Elements 4-10
Table 4-5 Insects That Cause Wood Damage 4-11

Table 4-6 Inspection Criteria for Expansion and Construction Joints 4-38
Table 4-7 Inspection Criteria for Reciprocating Compressors 4-43
Table 4-8 Inspection Criteria for Rotary Sliding Vane Compressors 4-44
Table 4-9 Inspection Criteria for Rotary Twin Lobe Compressors 4-45
Table 4-10 Inspection Criteria for Rotary Liquid Piston Compressors 4-45
Table 4-11 Inspection Criteria for Dynamic Compressors 4-46
Table 4-12 Inspection Criteria for Intercoolers and Aftercoolers 4-47
Table 4-13 Inspection Criteria for Traps 4-47
Table 4-14 Inspection Criteria for Absorption-Type Air Dryers 4-48
Table 4-15 Inspection Criteria for Refrigeration-Type Air Dryers 4-48
Table 4-16 Inspection Criteria for Compressed-Air Gas Storage Tanks 4-48
Table 4-17 Inspection Criteria for Small Gasoline, Diesel, or Propane Engines 4-49
Table 4-18 Inspection Criteria for Steam Distribution Systems 4-50
Table 4-19 Inspection Criteria for High-Temperature Water Distribution Systems 4-51
Table 4-20 Inspection Criteria for Instruments 4-52
Table 4-21 Inspection Criteria for Controls 4-52
Table 4-22 Inspection Criteria for Air Conditioning Systems 4-53
Table 4-23 Inspection of Lighting System Components 4-58
Table 4-24 Inspection Criteria for Running Motors 4-59
Table 4-25 Inspection Criteria for Motors After Being Shut Down 4-61
Table 4-26 Inspection Criteria for Deenergized Transformers 4-62
Table 4-27 Inspection Criteria for Energized Transformers 4-63
Table 5-1 Prevention of Deterioration of Structural Steel 5-6
Table 5-2 Recommended Routine Maintenance for Valves 5-25
Table 5-3 Recommended Routine Maintenance for Pumps 5-26
Table 5-4 Recommended Maintenance for Air Conditioning System Components 5-34
Table 5-5 Common Maintenance and Repair Procedures for Circuit Breakers 5-36
Table 5-6 Routine Maintenance of Lighting Equipment 5-37
Table 5-7 Routine Maintenance and Repair Procedures for ac/dc Motors 5-38
Table 5-8 Routine Maintenance and Repair Procedures for dc Motors 5-38
Table 5-9 Routine Maintenance and Repair Procedures for ac Motors 5-40
Table 6-1 Maintenance Repairs for Asphalt Surfaces 6-20

1 INTRODUCTION

1.1 Background

Because the ages of many nuclear units, fossil units, and U.S. Department of Energy (DOE) nuclear facilities exceed 40 years, the maintenance costs associated with process, administrative, and support facilities and infrastructure continue to rise. These buildings and other structures and facilities (OSFs), although not directly related to the generation of electricity or the primary mission of a DOE nuclear facility, are important in supporting the operation of each facility. In some cases, maintenance of these facilities and properties has not been planned and implemented to the same degree as those structures directly supporting the generation of power or mission-essential activities and processes. At other facilities, the maintenance has been deferred, has become backlogged, and is difficult to manage effectively.

1.2 Purpose

The purpose of this guide is to provide personnel at nuclear and fossil power plants and U.S. DOE nuclear facilities with a comprehensive treatment of support, administrative facilities, property maintenance, and OSFs such as building cooling towers, roads, parking lots, fences, bridges, utility poles, and sidewalks. The biggest challenge in this regard was consistently providing a reasonable level of detail regarding both the scope of items included and the inspection and maintenance activities required. Information learned from utility personnel and DOE facility maintenance managers during the development of this report suggested that the scope of buildings and system components for which these individuals were responsible varied significantly from site to site. The type of equipment also varied significantly. As such, there might be cases where some unique building element or system component has not been included in this report.

The report includes the following topics and areas of interest:

- A compilation of existing guidance and standards on facilities maintenance, failure mechanisms, and aging
- A compilation of criteria and standards that facilities maintenance managers can use to inspect a facility or building and/or system component
- Different inspection techniques, their advantages and disadvantages, and how to effectively use them

- The means for establishing the baseline condition from which to assess the facility or property
- Preventive and corrective maintenance processes for various building elements and system components (used in conjunction with each manufacturer's recommendations)

1.3 Scope

1.3.1 Scope of Facilities and Facility Components Described in This Report

The general scope of structures, systems, and components (SSCs) described in this report include major structural materials, facility finish materials, facility systems, and external systems as noted in Table 1-1.

Table 1-1
Scope of Structures, Systems, and Components

Major structural materials
• Reinforced concrete
• Structural steel
• Wood/timber
Facility finish materials
• Exterior materials
• Interior ceiling and wall materials
• Floors
• Roofs
• Windows and doors
• Coatings for exterior surfaces
Facility systems
• Water distribution systems
• Heating, ventilating, and air conditioning (HVAC) systems
• Electrical systems
• Conveying systems
External systems
• Walks, drives, curbs, and asphalt surfaces
• Runoff, drainage, and erosion control systems
• Fences
• Tanks

1.3.2 Scope and Organization of This Report

Section 2 provides an overview of facilities maintenance including a description of the types of maintenance typically encountered and the types of forces acting on facilities that cause aging and deterioration. Section 2 also provides a summary description of the various types of building elements included in this report.

Section 3 presents a detailed description regarding the various failure mechanisms for the building elements and related components introduced in Section 2. These failure mechanisms become the basis for the types and frequency of condition-based monitoring, inspections, and preventive maintenance activities described in the remainder of the report.

Section 4 provides detailed condition monitoring guidance and recommended inspection criteria for major building elements and system components that are commonly included within the scope of the facility maintenance manager's responsibility. Condition monitoring and inspection are considered key elements in this report; and as such, inspection criteria for a wide variety and scope of equipment and building elements are supplied.

Sections 5 and 6 present guidance for equipment, system, and building maintenance. Section 5 describes routine preventive maintenance activities that are often included in a facilities maintenance program. Section 6 provides the user with guidance regarding corrective maintenance and repairs.

Section 7 provides guidance regarding facilities maintenance management functions, including an analysis regarding the cost effectiveness of repair versus replacement. Section 8 lists the source documents and references used in compiling and developing this report.

Appendix A describes programmatic elements that can be useful to the facility maintenance manager who is attempting to establish a new program or enhance an existing program. Guidance is provided for facility identification and categorization, means for distinguishing real property from personal property (for example, process equipment), and prioritizing maintenance activities. Appendix B presents estimated design lives for various building elements and system components. Appendix C lists codes and standards related to the design, construction, and maintenance of facilities located at a power generating facility or a DOE nuclear facility. Appendix D contains a listing of all Key Points—bold-lettered boxes that succinctly restate information covered in detail in the surrounding text—and provides reference to their locations in the body of the report.

1.4 Integration of Guidance in This Report

This report includes detailed guidance and processes for effectively inspecting, maintaining, and repairing various types of building elements and components. However, the user of this report should recognize that the guidance provided should not usurp or replace the recommended practices typically provided by each specific product manufacturer. The intent is for the facilities maintenance manager to integrate and apply the guidance contained in this report, as necessary, to

develop a cost-effective program, and to use each manufacturer's product-specific recommendations as necessary in the implementation of that program.

Figure 1-1 illustrates the primary sources of guidance for a facilities maintenance manager. The technical manuals specific to each particular building element, component, or piece of equipment that are furnished by the product manufacturer should remain the primary source of guidance. In the absence of this product-specific information and guidance, the facilities maintenance manager can use the guidance in this report, which can be supplemented as needed with maintenance guidance from other EPRI technical reports. Finally, Figure 1-1 illustrates that in the vast majority of cases, the foundation for much of the recommended EPRI guidance is based on existing industry standards provided by numerous industry groups, as well as applicable industry codes, standards, and regulations. Listings of these industry groups as well as the related codes, standards, and regulations are provided in Section 8.4 and Appendix C of this report, respectively.

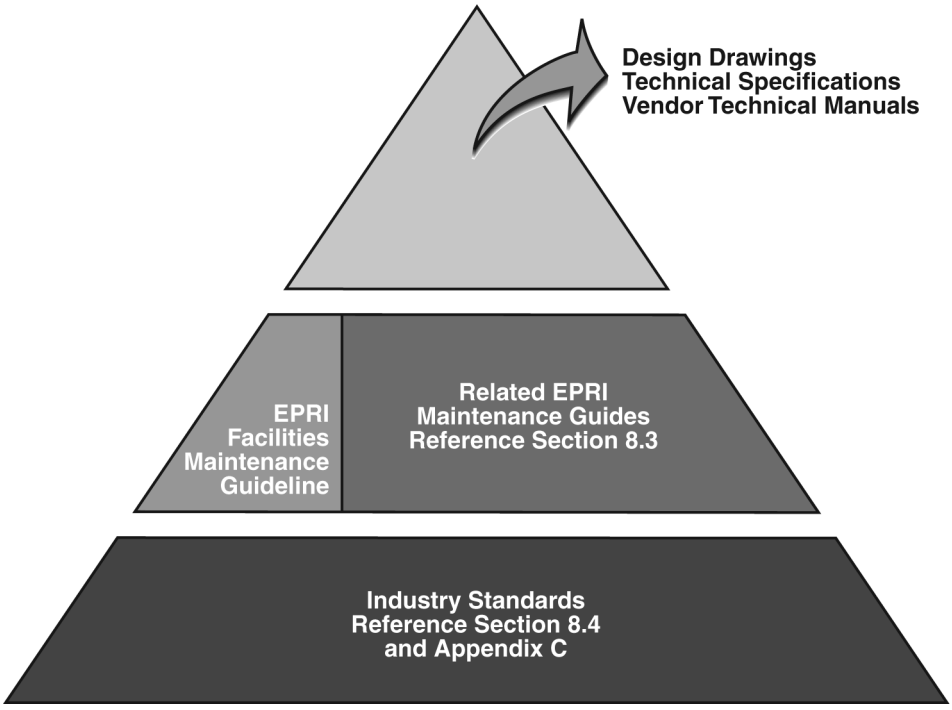


Figure 1-1
Integration of Maintenance Guidance
(Courtesy of Sequoia Consulting Group, Inc.)

1.5 Effective Use of the Guidance in This Report

The topic of this report, facilities maintenance, is very broad and can mean different things to different types of maintenance personnel. This guideline was written primarily for those individuals at a nuclear or fossil power plant who have been designated as being responsible for the maintenance of facilities and building elements not addressed in the existing maintenance program for power-generating SSCs. The focus for these individuals and the guidance that would

be most relevant to them is different from that of their counterparts at a U.S. DOE nuclear laboratory or research production facility.

It is difficult to predict which portions and sections of this report will be most relevant to each of these types of facilities maintenance managers. In general, however, the building elements that tend to be the most problematic and require the most attention, regardless of the general type of facility, are the following:

- Roofs
- Exterior surfaces and finishes that directly impact the building's general appearance
- HVAC systems affecting the habitability of the building
- Lighting systems that impact human performance
- Doors and windows that adversely effect habitability and human performance within the building
- Exterior coatings and paint
- Storm drains
- Utility systems (that is, light poles, compressed and breathing air, steam, electrical, and water distribution)

1.6 Acronyms

AAMA	American Architectural Manufacturers Association
AATCC	American Association of Textile Colorists and Chemists
ACI	American Concrete Institute
ACI	Asset condition index
AF&PA	American Forest & Paper Association
AFE	Association for Facilities Engineering
AHA	American Hardboard Association
AISA	American Iron and Steel Institute
AISC	American Institute of Steel Construction
AITC	American Institute of Timber Construction
AMCA	Air Movement and Control Association
ANSI	American National Standards Institute
APA	American Plywood Association
API	American Paper Institute
ARI	Air Conditioning and Refrigeration Institute
ASHRAE	American Society of Heating, Refrigeration and Air Conditioning Engineers

ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
AWC	American Wood Council
AWPA	American Wood-Preservers' Association
BIA	Brick Industry Association
BIA	Brick Institute of America
BOCA	Building Officials and Code Administrators International
CAS	Condition assessment survey
CRI	Carpet and Rug Institute
CRSI	Concrete Reinforcing Steel Institute
DASMA	Door and Access Systems Manufacturer's Association International
DHI	Door and Hardware Institute
DORCMA	Door Operator & Remote Controls Manufacturers Association
EFCOG	Energy Facility Contractors Group
EIFS	Exterior insulation and finish systems
EIMA	Exterior Insulation Manufacturers Association
FCI	Facility condition index
FGMA	Flat Glass Marketing Association
FIMS	Facility Information Management System
GA	Gypsum Association
GANA	Glass Association of North America
HVAC	Heating, ventilating, and air conditioning
IEEE	Institute of Electrical and Electronics Engineers
IESNA	Illuminating Engineering Society of North America
IFMA	International Facility Management Association
IMI	International Maintenance Institute
IRMAS	Inverted insulated roof material asphalt shingle
JIES	Journal of the Illuminating Engineering Society
LD+A	Lighting Design + Application
MRC	Maintenance and Reliability Center
NAAMM	National Association of Architectural Metal Manufacturers
NAGDM	National Association of Garage Door Manufacturers
NAPHCC	National Association of Plumbing/Heating/Cooling Contractors

NFPA	National Fire Protection Association
NFPA	National Forest Products Association
NHLA	National Hardwood Lumber Association
NMAC	Nuclear Maintenance Applications Center
NOFMA	National Oak Flooring Manufacturers Association
NOFMA	National Wood Flooring Association
NTMA	National Terrazzo & Mosaic Association, Inc.
NWWDA	National Wood Windows and Door Association
O&M	Operations and maintenance
OSFs	Other structures and facilities
PCA	Portland Cement Association
PCI	Precast/Prestressed Concrete Institute
PDI	Plumbing & Drainage Institute
PFMA	Plant and Facilities Maintenance Association
RCM	Reliability-centered maintenance
RPV	Replacement plant value
SDI	Steel Door Institute
SMACNA	Sheet Metal & Air Conditioning Contractors National Association
SMRP	Society for Maintenance & Reliability Professionals
SPRI	Single-Ply Roofing Institute
SSC	Structures, systems, and components
SSPC	Society for Protective Coatings
SSPC	Steel Structures Painting Council
TPI	Truss Plate Institute
UBC	Uniform Building Code
UL	Underwriters Laboratories, Inc.
U.S. DOE	U.S. Department of Energy

1.7 Key Points

Throughout this report, key information is summarized in "Key Points." Key Points are bold-lettered boxes that succinctly restate information covered in detail in the surrounding text, making the key point easier to locate.

The primary intent of a Key Point is to emphasize information that allows individuals to take action for the benefit of their plant. The information included in these Key Points was selected by Nuclear Maintenance Applications Center (NMAC) personnel, consultants, and utility personnel who prepared and reviewed this report.

The Key Points are organized according to the three categories: operations and maintenance (O&M) cost, technical, and human performance. Each category has an identifying icon to draw attention to it when reviewing the guide.



Key O&M Cost Point

Emphasizes information that results in reduced purchase, operating, or maintenance costs.



Key Technical Point

Targets information that leads to improved equipment reliability.



Key Human Performance Point

Denotes information that requires personnel action or consideration in order to prevent injury or damage or to ease completion of the task.

Appendix D contains a listing of all Key Points in each category. The listing restates each Key Point and provides reference to its location in the body of the report. By reviewing this listing, users of this guide can determine if they have taken advantage of key information that would benefit their plants.

1.8 Unit Conversions

Table 1-2 presents conversion factors used to convert values from English to Standard International units.

Table 1-2
Conversion Factors

Parameter	English to Standard International
Area	1 in^2 = 6.45 cm^2 1 ft^2 = 929 cm^2
Energy	1 HP = 745.7 watts
Length	1 in. = 2.54 cm 1 ft = 0.305 m 1 mil = 0.00254 cm 1 yd = 0.9144 m
Lighting	1 footcandle = 10.76 lumens/m^2
Pressure	1 lb/ft^2 = 4.8 kg/m^2 1 psi = 6.89 kPa
Temperature	1°F = (C x 9/5) + 32
Velocity	1 mph = 1.61 km/hr
Volume	1 qt = 0.95 liters 1 gal = 3.78 liters
Weight	1 lb = 0.45 kg 1 oz = 28.35 gm

2
FACILITIES MAINTENANCE OVERVIEW

2.1 Types of Maintenance

In the most general terms, *maintenance* can be defined as:

> "The act of keeping fixed assets in acceptable condition. It includes preventive maintenance, normal repairs, replacement of parts and structural components, and other activities needed to preserve the asset so that it continues to provide acceptable services and achieves its expected life. Maintenance excludes activities aimed at expanding the capacity of an asset or otherwise upgrading it to serve needs different from, or significantly greater than, those originally intended." [2]

A brief description of different types of maintenance is provided in this section. A more detailed description is provided in Appendix A.

Preventive maintenance. Actions performed on a time- or machine-run-based schedule that detect, preclude, or mitigate degradation of a component or system with the aim of sustaining or extending its useful life through controlling degradation to an acceptable level.

Predictive maintenance. Measurements that detect the onset of a degradation mechanism, thereby allowing casual stressors to be eliminated or controlled prior to any significant deterioration in the component physical state.

Reliability-centered maintenance (RCM). A process used to determine the maintenance requirements of any physical asset in its operating context.

Reactive maintenance. Basically the "run it till it breaks" maintenance mode; often referred to as corrective maintenance. No actions or efforts are taken to maintain the equipment as the designer originally intended to ensure that design life is reached.

Deferred maintenance. Maintenance that was not performed when it should have been or was scheduled to be, and which, therefore, is put off or delayed until a future time.

This report focuses primarily on using a combination of preventive, predictive, and RCM techniques for the effective maintenance of buildings, facilities, and system components. In some cases, these activities include minor repairs, which in and of themselves might be considered by some to be reactive or corrective maintenance. In general, however, this report does not support heavy reliance on reactive and corrective maintenance practices.

A secondary goal of this guide is to describe ways in which deferred maintenance should be prioritized and conducted, but not necessarily to provide any particular user of this report with cost-effective solutions to existing maintenance backlogs. Rather, those users facing extensive amounts of deferred maintenance should integrate the guidance contained in this report into their existing preventive maintenance program for facilities and buildings.

2.2 Types of Forces Acting on Facilities

A force is any effect that tends to change the state of motion or the shape of any material. Examples include dead weight of a material, moving objects, push or pull produced by expansion or contraction due to temperature change, and swelling and shrinkage due to moisture changes. Forces are either static or dynamic. Static forces are those forces that are always present, such as the dead weight of the element itself. Dynamic forces are moving forces such as wind or an ocean wave hitting a pier.

Forces are induced by external loads. The two basic types of loads are dead loads and live loads. A dead load is one that is permanent, such as the weight of an air conditioning unit on a roof. Live loads are occasionally applied loads, such as people walking on a floor.

Every material must resist both dead and live loads. An example of this is an administrative building, where on any one floor there exists a live load made up of the people and furnishings occupying the floor space and a dead load made up of the weight of the finish floor material.

Table 2-1 provides a summary of the forces typically exerted on facilities.

Table 2-1
Summary of Forces [1]

Type of Force	Effect and Application
Gravity	Weight of materials and permanently attached items: dead loads. Weight of building occupants, moveable contents, and snow: live loads applied in a downward direction.
Wind	Wind velocity, applied horizontally from any direction.
Earthquake	Produced by movement of an internal earth mass that produces shock waves, resulting in shaking of the ground. Random vertical and horizontal applications.
Blast	Due to explosions, horizontally applied.
Hydraulic and pneumatic pressure	Liquid and gas forms, applied horizontally and/or vertically.
Thermal expansion and contraction	Due to temperature variations in materials. Internal forces applied in vertical and horizontal directions.

2.3 Scope and Types of Building Elements

2.3.1 Major Structural Elements

The three general types of major structural elements described in this report are reinforced concrete, structural steel, and wood/timber.

2.3.1.1 Reinforced Concrete

Because it is made up of more than one type of material, reinforced concrete is referred to as a nonhomogeneous material. Unlike steel or wood, it is susceptible to a wider variety of failure mechanisms. Reinforced concrete is typically made up of a combination of the following materials of construction:

- Hydraulic cement
- Coarse aggregate
- Fine aggregate
- Mixing water
- Admixtures
- Reinforcement

For this report, reinforced concrete is described in the context of any of the following plant applications and/or installations:

- Building walls, floors, ceilings, stairs, ramps, loading docks, and decks
- Structural columns and beams
- Sumps
- Drainage ditches
- Secondary containment structures for hazardous materials
- Sidewalks, curbs, and walkways

2.3.1.2 Structural Steel

For this report, structural steel is categorized into two major categories, structural members and connections. Included in each category are the following types of structural elements:

Structural Members

- Roof trusses
- Open web joists
- Platform supports
- Equipment supports
- Stairs
- Bearing and base plates
- Siding girts
- Roof purlins
- Bridging
- Steel decking
- Bracing (vertical and horizontal)
- Knee braces
- Columns
- Crane rails
- Beams and girders
- Plate and shells
- Stacks

Connections

- Bolts
- Welds
- Anchor bolts
- Rivets
- Splices (beams and columns)
- Connecting plates and angles

2.3.1.3 Wood/Timber

Wood/timber elements make up many portions of existing facilities and buildings currently in use at an electric generating plant. For this report, the structural and building elements that can be fabricated from wood/timber include the following:

- Sills and plates
- Beams and girders (ledgers)
- Rafters
- Joists
- Columns (posts)
- Bridging
- Headers
- Studs
- Lintels
- Stairs
- Wood trusses
- Nailers
- Finish wall and ceiling covering
- Finish floor covering
- Subfloors
- Fascia and related trim
- Finish trim
- Other millwork
- Laminated wood members

2.3.2 Facility Finish Materials

2.3.2.1 Exterior Materials

Wood exteriors. Wood exterior surfaces can be constructed of shingles, weatherboard siding, or plywood.

Metal exteriors. Metal exterior surfaces can be constructed of corrugated iron or steel, aluminum, enamel-coated steel, or protected metal. Protected metal roofing and sidings are of the standard-corrupted or deep-corrupted types, with steel core protected at the factory with coatings or a combination of coverings or coatings. The sheets are resistant to flame spread. The weather surfacing is weather resistant, water repellant, and resistant to fumes, chemicals, and corrosion. Color pigments used in color coats are heat and light stable, and chalk resistant. The sheets are typically furnished complete with all flashings, fastenings, and accessories. Interior and/or exterior surfaces of the sheets are provided with bituminous (black) or colored synthetic resin, factory-applied weather surfacing. Protective coverings and/or coatings are applied by one of the following methods:

- **Type A.** The cleaned steel core is dipped in a bath of molten zinc, fusing the zinc to the steel. While the zinc is in a molten state, a layer of felt is pressed over it on each side of the sheet, squeezing the felt fibers into the zinc. The exterior and/or interior surface is finished with a heavy bituminous compound or a color coating of synthetic resin.
- **Type B.** The cleaned steel core is given a phosphatizing treatment, coated with a rust-inhibitive primer, and coated with a resinous adhesive. A layer of impregnated felt is rolled onto both sides of the sheet with the application of heat and pressure. The sheet is then given a protective coating of bituminous compound or alkyd-resin colored compound.
- **Type C.** The cleaned steel core is coated on all surfaces with a rust-inhibitive coating. The sheet is then heated and coated with adhesive. After application of the second coat, a layer of mineral mica is applied by heat and pressure to both sides of the sheet. A synthetic-resin color coating can be applied over the bituminous compound coatings.

Masonry and concrete exteriors. Concrete and masonry exteriors include bricks, granite, and limestone. For maintenance purposes, glass block walls and stucco can also be included in this general category.

Mineral-surfaced board exteriors. Developments in combining chemical and mineral elements have produced hard-surfaced, weather-resistant materials for exterior wall finishes. These materials require little maintenance except to keep fasteners secure and to remove stains from other sources.

2.3.2.2 Interior Ceiling and Wall Materials

Interior walls are either plastered (wet walls) or covered with materials such as gypsum wallboard, plywood, tongue-and-groove wood paneling, tile, or glazed-face masonry. Partitions can be of plywood, plasterboard, hard-pressed fiberboard, structural clay tile, gypsum block,

metal, and glass. Ceilings are usually made of gypsum board, plastered, paneled with wood, or covered with sheet metal or acoustical materials. In this report, the maintenance and repair procedures for wall and ceilings made up of the same materials are identical, except for the amount of time and the required equipment necessary.

Tables 2-2 and 2-3 provide lists of commonly used interior finish and covering materials for walls, respectively, and key maintenance and design parameters for each type.

Table 2-2
Interior Finishes: Wall Materials [1]

Wall or Ceiling Material	Insulating Value	Resistance to Dampness	Resistance to Grease and Dirt	Durability	Ease of Application	Sound Deadening	Ease of Cleaning
Acoustical tile	Good	Poor	Fair	Fair	Excellent	Good	Fair
Brick or block	Poor	Fair	Poor	Excellent	Fair	Good	Poor
Corrugated plastic sheeting	Good	Excellent	Excellent	Excellent	Fair	Fair	Fair
Glass blocks	Good	Excellent	Excellent	Excellent	Fair	Fair	Excellent
Plaster: bare	Fair	Poor	Poor	Fair	Poor	Fair	Poor
Plastic blocks	Good	Excellent	Excellent	Good	Fair	Fair	Excellent
Stone and artificial stone	Poor	Good	Poor	Excellent	Fair	Good	Poor
Wallboards and plasterboards							
• Asbestos board	Good	Excellent	Poor	Excellent	Good	Good	Excellent
• Fiberboard (unfinished)	Excellent	Fair	Poor	Fair	Good	Excellent	Poor
• Hardboards (prefinished)	Fair	Excellent	Excellent	Excellent	Excellent	Fair	Excellent
• Insulating wallboards	Excellent	Fair	Poor	Fair	Good	Excellent	Poor
• Perforated hardboards	Poor	Good	Good	Excellent	Excellent	Poor	Fair
• Plasterboard (unfinished)	Fair	Poor	Poor	Excellent	Good	Fair	Poor
Wood							
• Plywood (prefinished)	Fair	Fair	Fair	Good	Good	Fair	Good
• Plywood (unfinished)	Fair	Fair	Poor	Good	Excellent	Fair	Poor
• Solid hardwood (unfinished)	Good	Good	Poor	Good	Fair	Fair	Poor
• Solid softwood (unfinished)	Good	Fair	Poor	Good	Fair	Fair	Poor

Table 2-3
Interior Finishes: Wall Coverings [1]

Wall Material	Resistance to Dampness	Resistance to Grease and Dirt	Durability	Ease of Application	Ease of Cleaning
Cork	Poor	Poor	Fair	Good	Excellent
Enamel on felt	Excellent	Excellent	Fair	Good	Excellent
Glass sheets	Excellent	Excellent	Fair	Fair	Excellent
Leather	Good	Good	Fair	Good	Excellent
Linoleum: inlaid	Excellent	Excellent	Good	Good	Excellent
Paint					
• Clear finishes (varnish, shellac, lacquer)	Good	Good	Good	Good	Excellent
• Linseed oil	Good	Fair	Good	Excellent	Good
• Paints mixed with water	Poor	Poor	Fair	Excellent	Poor
• Paints with oil, rubber alkyd; emulsion based	Fair	Good	Good	Excellent	Excellent
Tiles					
• Asphalt, rubber	Excellent	Good	Good	Good	Excellent
• Glazed ceramic	Excellent	Excellent	Excellent	Fair	Excellent
• Metal	Excellent	Excellent	Excellent	Good	Excellent
• Plastic	Excellent	Excellent	Excellent	Good	Excellent
• Unglazed ceramic	Excellent	Good	Excellent	Fair	Good
Wallpaper					
• Coated fabrics	Good	Good	Good	Good	Excellent
• Nonwashable	Poor	Poor	Poor	Good	Poor
• Scrubbable, fabric backed	Excellent	Excellent	Good	Good	Excellent
• Thermosetting plastic sheets	Excellent	Excellent	Good	Good	Excellent
• Uncoated fabrics	Fair	Fair	Poor	Good	Poor
• Washable	Fair	Poor	Fair	Good	Good

2.3.2.3 Floors

The repair and maintenance of floor coverings are among the most important aspects of building operations, because floor coverings are the most used and abused portions of a structure. From a statistical standpoint, floors probably receive about 90% more wear than any other part of a building and account for about 50% of the overall cost of the building operations. Therefore, it is of utmost importance that the proper flooring material is carefully selected and maintained. Table 2-4 contains a list of some of the major types of flooring materials available, including their advantages and disadvantages.

Table 2-4
Types of Flooring Materials and Their Relative Characteristics [1]

Flooring	Location*	Resistance to Abrasion	Resistance to Indentation	Ease of Maintenance	Durability
Resilient					
• Asphalt tile	B-O-S	Poor	Poor	Fair	Good
• Linoleum	S	Fair	Poor	Fair	Fair
• Vinyl composition tile	B-O-S	Poor	Poor	Good	Good
• Rubber tile	B-O-S	Fair	Excellent	Poor	Good
• Homogenous vinyl tile	B-O-S	Fair	Good	Good	Excellent
• Cork tile	S	Fair	Fair	Good	Poor
• Backed vinyl tile	B-O-S	Fair	Good	Good	Excellent
• Vinyl cork tile	S	Fair	Good	Good	Fair
Wood • Oak strip • Maple strip • Block • Parquet block	B-O-S	Fair	Good	Good	Good
Carpet • Polypropylene • Nylon • Antron nylon • Acrylic • Wool	B-O-S	Good	Good	Good	Good
Formed in place • Mastic • Polychloroprene • Epoxy • Polyurethane • Polyester • Silicone	B-O-S	Good	Good	Excellent	Excellent

Table 2-4 (cont.)
Types of Flooring Materials and Their Relative Characteristics [1]

Flooring	Location	Resistance to Abrasion	Resistance to Indentation	Ease of Maintenance	Durability
Masonry • Concrete • Magnesite	B-O-S	Good	Good	Good	Good
• Brick • Ceramic tile	B-O-S	Good	Excellent	Poor	Poor
• Terrazzo • Slate	B-O-S	Good	Excellent	Excellent	Excellent

* Key for various applications: B = Below grade, O = On grade, S = Suspension

Resilient flooring. Resilient floor coverings are available in several forms, the first being a sheet that can be bought in several widths and delivered in rolls. Resilient flooring can often be obtained in tile form in either 9-in. or 12-in. squares. Resilient floors are somewhat porous and they tend to be softer than other flooring materials; therefore, dirt is more easily ground into this type of flooring by foot traffic. This foot traffic causes an abrasive action that scratches the surface and fills the pores with dirt. This dirt is not easily removed by the everyday sweeping process. Types of resilient floor coverings include the following:

- **Asphalt tile.** Asphalt tile is considered to be moisture- and decay-proof. However, it is easily indented by heavy or pointed objects. Oil, grease, gasoline, naphtha, turpentine, carbon tetrachloride, and kerosene are all harmful to asphalt tile. Asphalt tile fades from direct sun exposure and softens due to high temperatures. Too much exposure to low temperatures results in brittleness and cracking, especially if the subfloor is not smooth and rigid.
- **Cork tile.** Cork tile is the most porous and resilient of all of the floor coverings. Cork flooring is not slippery like many other tiles are, especially when waxed. Cork has a natural tendency to fade and discolor. Cork is good insulation, practically odorless, and has no tendency to splinter or warp. Substances such as naphtha, gasoline, oil mops, and sprays are harmful to cork.
- **Linoleum tile.** Linoleum tile has a load limit of about twice that of resilient tiles, similar to asphalt tile. All forms of alkali, along with grease and oils, are injurious to linoleum. Highly alkaline materials deteriorate linoleum, causing brittleness. In addition, color fading, whitening, and eventually disintegration occur due to contact with highly alkaline materials. As is true for other types of resilient flooring, excess amounts of water accumulation damage the tile.
- **Rubber tile.** Rubber tile is somewhat resistant to alkali, acids, and stains. It is also soundproof and slip resistant. The tendency for it to crack is minimal, and it can withstand large amounts of pressure.

- **Vinyl composition.** Vinyl composition tile is a type of vinyl tile that has many advantages over asphalt tile. It is immune to mineral solvents, oils, and greases as well as alkalis and acids. It has a higher indentation resistance than asphalt tile, but it still indents under heavy static loads. It is generally decay- and mildew-proof.
- **Vinyl plastic tile.** Vinyl plastic tile has all the qualities of vinyl composition tile, and it also has a higher indentation resistance. Vinyl tiles are the most durable, have excellent resistance to grease, and are seemingly unaffected by high alkaline cleaners. The biggest disadvantage of vinyl tiles is that they permanently show many types of burn marks. Depending on the wear of the tile, it might not need to be sealed.



Key Human Performance Point

Some older tiles contain asbestos, which requires special measures for personnel protection and the implementation of numerous environmental regulations and statutes upon their removal.

Masonry floors. Masonry floors are composed of such materials as natural stone, brick, and ceramic tile. They also include poured masonry floors, such as concrete and terrazzo. Floors made of such materials are hard and durable, and are available in a wide range of colors, patterns, textures, and designs. They are especially suited, when installed properly, for use in areas intended for heavy traffic. These floors are especially resistant to staining and to deterioration by solvents, acids, and alkalis. Types of masonry floor coverings include the following:

- **Ceramic tiles.** Ceramic tile is available in either a glazed or unglazed surface. The unglazed variety is more widely used for floors. Both types are very dense, hard, and nonporous. Ceramic tiles can be used both indoors and outdoors. The three varieties that are often used for floors are ceramic mosaic tile, quarry tile, and pavers. The tile is available in many shapes, sizes, and patterns.
- **Concrete floors.** A concrete floor is smooth, one-piece, fire-resistant, and low in maintenance cost. It also stands up better to heavy floor traffic than most floorings. However, concrete lacks the color and general appearance that many finishes have. This is of utmost importance when appearance is a major consideration. A concrete floor should be sealed whether or not a finish flooring is to be installed on top of it.
- **Terrazzo.** Terrazzo has a high strength, is termite proof, cool in the summer, and warm in the winter, easy to maintain, and long lasting. It is also noted for its beauty. There are basically two types of terrazzo flooring. The first type is a mixture of Portland cement and marble chips. The second type is sometimes called thin terrazzo and is a mixture of an epoxy-type resin and marble chips. It is generally safe to assume that if there are metal divider strips, the terrazzo is probably the Portland cement type. Granolithic floors are similar to terrazzo, but they are different in that granite chips are used in place of marble chips. This type of floor does not usually have metal dividers.
- **Magnesite.** Magnesite floors, sometimes referred to a oxychloride, are very durable surfaces. The surface is extremely high in resistance to grease and oil, but has a poor resistance to water. Besides being durable, magnesite floors are strong, noncombustible, economical, dimensionally stable, and flexible. A variety of coloring and surface textures is possible with this type of flooring.

- **Slate tile.** Slate tile floors are very suitable for areas subjected to heavy traffic because of their durability and ease of maintenance. However, slate tile tends to be slippery when wet. If the area is often subject to wetness, a covering surface such as a rubber mat should be provided or this type of tile should not be used. When this tile is used indoors, the surface should be sealed with a penetrating-type sealer as a base coat, and then covered with a surface-type sealer to prevent dusting.
- **Brick flooring.** Using brick for floors is relatively economical. Brick is resistant to abrasion and has a relatively low maintenance cost. The best type of brick to use is a hard, dense, vitrified brick. Porous brick requires more maintenance because it has a greater tendency for discoloration and staining. After the brick is in place and cured, it is best to seal it with two coats of commercially available sealer. When this is done, it can be polished for longer wear.

Metal floors. Metal floors are usually composed of sheet, plate, and grating.

Seamless floors. Seamless floors are one-piece synthetic resins poured-in-place plastic floors that are tough, colorful, durable, and nearly maintenance free. There are many types of seamless flooring, depending on the basics of the sealer primers. The greatest asset of seamless floors is their durability. Scratches in the top surface eventually occur, especially in heavy traffic areas, and dull the finish.

Wood floors. Wood flooring is durable, decorative, warm, versatile, and fairly easy to maintain and restore to its original appearance. Wood floors come in many forms. The principal forms are strips, planks, block, and parquet. The two basic types of species available in wood flooring are the soft woods (such as pine) and the more common hardwoods (such as oak, beech, birch, and maple).

Carpets. Rugs or carpets are installed in a building for floor covering to provide a softness underfoot, warmth, quiet, and beauty. They also offer other functional, decorative, and psychological values.

2.3.2.4 Roofs

The roofing system is one of the most important parts of any building. A roofing system includes the structural roof deck and a field-fabricated weathering surface such as shingles or metal, built-up, or single membranes. Some of the considerations in the design stage that influence roof selection are the type of structure, the configuration of the roof deck surface, the forces the roof must resist, and the size of the area. A roofing system requires several components to provide resistance to environmental elements and forces that are detrimental to the building and its contents.

Roof decks. Commonly used roof deck materials are the following:

- Wood
- Metal
- Cementitious wood fiber
- Structural concrete
- Lightweight insulating concrete
- Gypsum

Metal, structural concrete, and lightweight insulating concrete are the most commonly used. Metal and structural concrete normally require the addition of insulation to the deck. Lightweight insulating concrete is self insulating and might not require any supplementary insulation, depending on the prevailing building codes.

Gypsum is used mainly for its fireproofing qualities and relatively low resistance to heat transmission. However, because gypsum is slow to dry during the curing process, it tends to extend the construction period. Therefore, its use might be limited in power plant facility applications.

Roof coverings. The various types of roof covering available are the following:

- **Shingles.** Composition asphalt, fiberglass, tile, slate, or metal
- **Sheet metal.** Copper, zinc-coated galvanized steel, various alloys, and commercial coating
- **Membranes.** Elastomer sheeting, liquid silicone rubber, mineral-surfaced composition rolled roofing, and field-fabricated (built-up) membrane consisting of reinforcing plies of felt or fiberglass felt embedded in bitumen and covered with a protective surface

Table 2-5 provides a listing of available types of roofing and roofing sandwich components.

Table 2-5
Available Roofing and Roofing Sandwich Components [1]

Flat Roofing Types of Components	Description
Built-up (membrane asphalt)	Asphalt reinforced with cellulose felt plies and covered with embedded gravel or slag for protection wearing surface.
Coat tar pitch	Coal tar pitch reinforced with cellulose plies and covered with embedded gravel or slag.
Single-ply sheeting	Thermosetting or thermoplaned material placed over insulated roof surface.
Fiberglass reinforced	Asphalt reinforced with fiberglass mat (felt) and covered with embedded gravel or slag.
Sheet metal	Flat seam. Similar application to standing seam except that all joints are flat and soldered.
Modified bitumen	Composite sheet of two or more materials and additives. Similar to built-up roofing except that the individual plies are factory-laminated and the modified bitumen is applied in one layer.
Spray-on foam and coating	Special formulated coating(s) applied to urethane foam.
Sloping Roof Types of Components	**Description**
Composition shingles	245 to 300 lb/ft^2. Asphalt composition shingles: strip or individual over asphalt-saturated felt underlay.
Other shingle materials	Wood, tile, slate, and metal: all applied over asphalt felts.
Mineral-surfaced composition	Applied over asphaltic felt underlay.
Roll roofing	
Sheet metal	Standing seam, lock seams, and cleats installed over rosin paper. Cleats nailed to wood deck or screwed through 1/2-in. rigid insulation on metal deck.

2.3.2.5 Windows and Doors

Windows and doors should be given the same amount of attention as walls, ceilings, and floors. Windows provide the required amount of natural light and they shield the occupants from the elements. Glass, which is utilized in most windows, is a transparent, nonabsorbent material that is resistant to most acids and alkalines. The types of windows that are available and can be found installed in facilities and buildings at power generating stations are the following:

- Fixed
- Double hung

- Casement
- Horizontal sliding
- Awning
- Hopper

Items common to all types of windows include the following:

- Frames
- Sashes (glass frames)
- Hardware
- Weather stripping

Two types of doors are typical. The first is the interior door that controls the passage of sound and view between interior work spaces. The second type is the exterior door that provides entrance into the building with control of weather, view, and privacy. The major categories of doors include the following:

- Flush (hollow core or solid core)
- Stile and rail
- Accordion and folding
- Bypass

Exterior doors are subject to more abuse and weathering than interior doors. However, for both types, defects and corrective measures are similar.

2.3.2.6 Coatings for Exterior Surfaces

Painting is probably one of the most used and misused preventive maintenance procedures. Painting done at too frequent an interval is just as bad, if not worse, than painting at too infrequent an interval. It is often better to wash the surface than to repaint. If considering painting, one should remember that more than one painting system is often suitable for a combination of surfaces, the environment, and service required. And for surface preparation, the choice of equipment and the method of application can vary according to the severity of the exposure, the coating used, and the conditions under which it is applied. Each of these factors contributes to the effectiveness of the completed job.



Key Human Performance Point

Some older paints contain PCBs for fire retardancy, which require special measures for personnel protection and the implementation of numerous environmental regulations and statutes upon their removal.

Many nuclear power plants have developed extensive coatings programs, and typically have an individual designated as the coatings specialist. This individual should be considered a source of guidance for the selection, surface preparation, inspection, and application of any coating used during routine facilities maintenance. Additional guidance in this regard can be found in EPRI report 1003102, *Guideline on Nuclear Safety-Related Coatings, Revision 1 (Formerly TR-109937)* [3].

Paint serves as a protective shield between the base construction materials and the elements that attack and deteriorate them. Painting, when regularly programmed, offers long-range protection that extends the useful life of the structure. Besides protection, additional purposes of painting are the following:

- To maintain a sanitary and clean environment
- To improve illumination and visibility
- To ensure a safe and efficient environment
- To improve the building's appearance
- To provide fire retardancy

A lasting appearance can be maintained at minimum cost by the following:

- Adequately protecting the surface
- Using paints for finish coats that retain—to a maximum—their color and gloss

Relative to building housekeeping, paint coatings provide smooth, nonabsorptive surfaces that are easily washed and kept free of dirt. The coating of rough or porous areas seals out dust and grease that would otherwise be difficult to remove. In addition, paint coatings reveal built-up foreign substances, thereby indicating the need for better housekeeping practices. Some paints delay the spread of fire in a system, confining it to its origin. Use of fire-retardant paints is restricted to appreciable areas of highly combustible surfaces and for other select uses. Fire-retardant paints should not be considered acceptable substitutes for conventional paints.

Paint materials. Knowledge of the types of materials used for painting is useful in determining their capabilities and limitations. The sound reasons for the existence of each coating specification become more apparent with some insight into the composition of the various types specified. When determining which type of coating to use, several parameters should be considered:

- Area to be painted
- Surface(s) to be painted
- Substrate(s) to be painted
- Reason why painting is to be done
- Conditions under which painting is to be done

Relative to any one type of coating material, the facilities maintenance manager should evaluate the characteristics and product information shown in Figure 2-1.

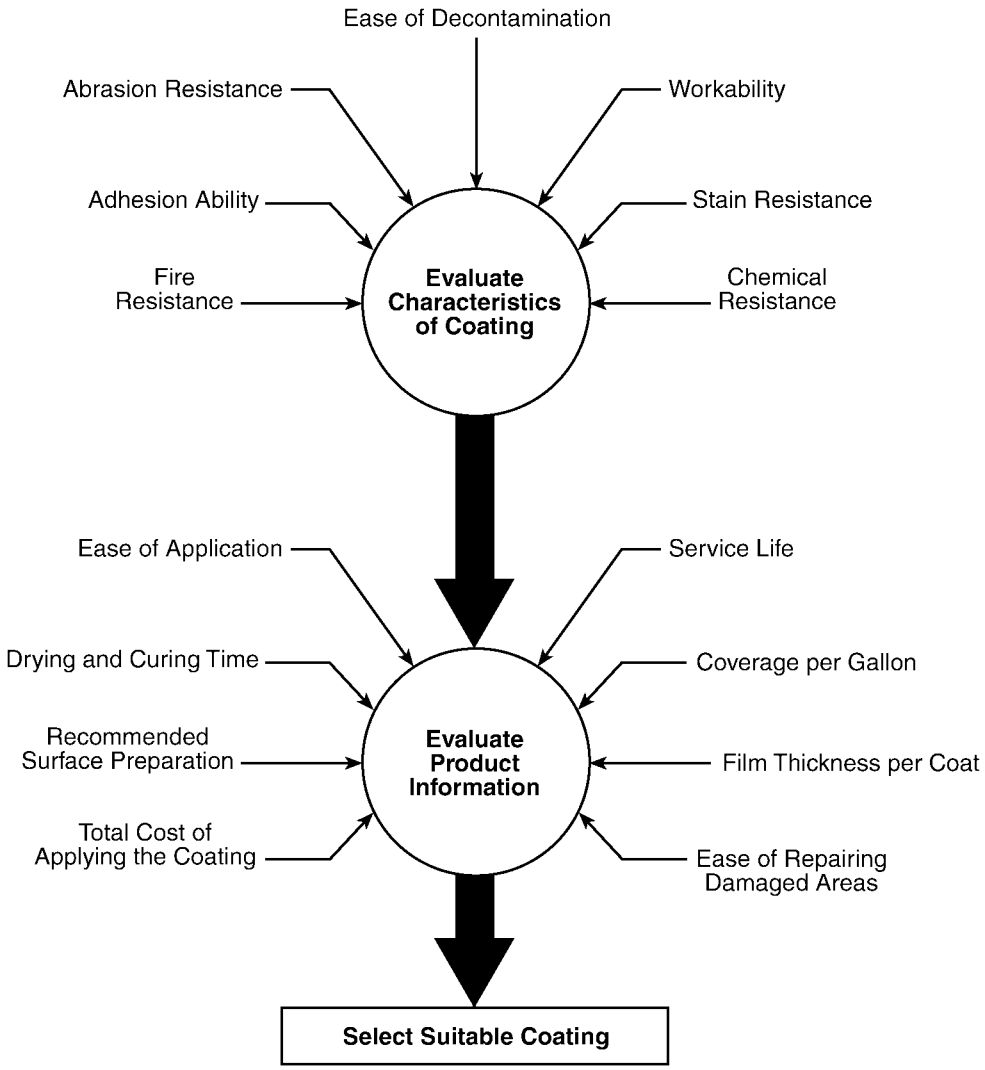


Figure 2-1
Characteristics and Product Information of Paint Material/Coatings [1]

Table 2-6 lists paints available for typical exterior building exposure that are commonly used on facilities at a power generating station.

Table 2-6
Paints Available for Typical Exterior Building Exposure [1]

	Oil or Oil-Alkyd	Cement Powder Paint	Exterior Clear Finish	Aluminum Paint	Wood Stain	Roof Coating	Trim Paint	Porch and Deck Paint	Primer or Undercoater	Metal Primer	Latex	Water-Repellent Preservative
Masonry												
Asbestos block	X*	X		X					X		X	
Brick	X*	X		X					X		X	X
Cement and cinder block	X*								X		X	
Concrete and masonry porches and floors								X			X	
Coal tar felt roof						X						
Stucco	X*	X		X					X		X	
Metal												
Aluminum Windows	X*			X			X*			X	X*	
Copper surfaces			X									
Galvanized surfaces	X*			X*			X*			X	X*	
Iron surfaces	X*			X*			X*			X	X*	
Metal roof	X*									X	X*	
Metal sliding	X*			X*			X*			X	X*	
Steel windows	X*			X*			X*			X	X*	
Wood												
Clapboard	X*			X					X		X*	
Natural wood siding and trim			X		X							
Shutters and other trim	X*						X*		X		X*	
Wood frame windows	X*						X*		X		X*	
Wood porch floor								X				
Wood shingle roof					X							X

X = Applicable
* = A primer, sealer, or fill is necessary before the finish coat is applied.

Other types of coatings. Besides paint, other types of coatings are available for special uses. Surface preparation, type of material, exposure conditions, method of applying the coating, and follow-up inspections are just as critical as for painting. Some of the other major types of coatings encountered in routine facilities maintenance programs are the following:

- Abrasion-resistant finishes
- Anti-sweat coatings designed to prevent condensation of water on cold surfaces, such as water pipes
- Bituminous finishes
- Fire-retardant paints
- Heat-resistant paints
- Mildew-resistant (fungi-resistant) paints
- Nonslip coatings
- Odorless paints
- Textured finishes
- Chemically-resistant coatings and liners used on secondary containment structures

2.3.3 Facility Systems

The guidance provided in this report regarding the maintenance of facilities systems is presented in general terms, because it is impossible to cover in detail the various types of system materials and all of the component accessories produced by the numerous manufacturers. Most manufacturers provide instructions, diagrams, drawings, and photographs with their products.

Where applicable, other EPRI reports are referenced that include routine maintenance, inspection, troubleshooting, and repair for major system components. Each user should also consider existing plant procedures that address maintenance practices for component types common to both facilities maintenance and primary system maintenance.

The scope of systems and components assigned to the facilities management organization varies from site to site. As such, each facilities maintenance manager should know the scope of SSCs for which they are responsible and which SSCs are maintained by others.

2.3.3.1 Water Distribution Systems

At most power generating facilities and DOE process facilities, a maintenance program for plumbing systems encompasses several types of subsystems and components:

- Fresh and waste water systems
- Fixtures
- Valves and faucets
- Pumps
- Deionized water or laboratory water

At some sites, the maintenance of the fire protection systems and related equipment can also be the responsibility of the facilities maintenance manager. In those cases, the facilities maintenance manager should use the guidance provided in EPRI report 1006756, *Fire Protection Equipment and Surveillance Optimization* [4]. Additional guidance can also be found in the related National Fire Protection Association (NFPA) standards.

2.3.3.2 Heating, Ventilating, and Air Conditioning Systems

HVAC systems control the flow of air within facilities to achieve a specific temperature, pressure, and humidity level necessary for equipment and personnel in those buildings to perform their designated functions. They can also be used for contamination control by creating pressure differentials in various rooms, and flow rates from low-contamination into high-contamination areas. For this report, the HVAC systems described are the following:

- **Facility or building ventilating and exhaust air systems.** These systems typically include ducts, fans and blowers, dampers, and louvers.
- **Building heating systems.** These systems typically include forced warm-air systems, gravity warm-air systems, steam systems, hot-water systems (including water heaters), oil-fired burners, pressure-atomizing burners, vertical-cup burners, gas-fired burners, and electric heaters.
- **Pneumatic systems.** These systems include reciprocating and rotary air compressors and air dryers.
- **Air conditioning systems.** These systems can include compressors, chillers, and ductwork.

2.3.3.3 Electrical Systems

Electrical distribution systems. The distribution system typically consists of substations, main feeders, subfeeders, panel boards, and branch circuits, along with any needed switch gear and fusing devices. The main feeders, subfeeders, and branch circuits are nothing more than two or more wires enclosed in some sort of protective covering such as plastic, metal, or both (in the case of a conduit).

Fuses protect the wiring system and electrical equipment from short circuits or overloads. The fuse should be of an amp rating that is consistent with the rating of the circuit that it is protecting. A circuit breaker is like a fuse, but it can be repaired. In most instances, if a circuit breaker has been opened due to an overload, all that is necessary is to reset it. However, at times the overloaded circuit breaker must be replaced, which is more costly than replacing a blown fuse. Switches are devices used to break the circuit integrity and stop the flow of electricity in the circuit. Distribution panels and cabinets house the electrical equipment so that it can be operated, maintained, and repaired safely.

Lighting systems. Each lighting system is designed to produce a specific level of illumination adequate for those working in the area. The amount of illumination provided starts to decrease almost as soon as it is put into operation as a result of dirt accumulation on the lamps and the reflective surfaces such as walls and ceilings.

The five primary types of lighting used are the following:

- **Incandescent lamps.** Fixtures are designed for particular lamp sizes and finishes. Care should be taken to not exceed the wattage of the particular fixture. Incandescent lamps yield maximum lighting economy when line voltage is at or near the designated voltage printed on the bulb.
- **Fluorescent lamps.** The three general types of 40-watt fluorescent lamps are instant start; preheat, rapid start; and preheat lamp. They all have nearly the same physical dimensions but different internal construction. The instant-start lamp operates satisfactorily with an instant-start ballast, burns off the ballast in a rapid-start circuit, and the lamp does not light in a preheat circuit. The preheat, rapid-start lamp operates satisfactorily in either the preheat or rapid-start circuits. It has a very short lamp life in an instant-start circuit. A preheat lamp has a very short lamp life in an instant-start circuit and has poor starting in a rapid-start circuit.
- **Mercury lamps.** Mercury lamps have the best-maintained output. Long average life is a primary characteristic of most mercury lamps. Mercury lamps are also extremely economical to use where high footcandles of illumination are desired.
- **Low- and high-pressure sodium lamps.**
- **Metal halide lamps.**

Motors. Good maintenance of motors consists basically of cleanliness and lubrication. A dirty motor does run, but at higher than normal temperatures, which tends to shorten the life of the insulation and the bearings.

Batteries. Batteries are devices that store electrical energy. Like any other type of electrical equipment, batteries should be placed under a preventive maintenance program.

Transformers. Transformers are devices that convert ac power into dc power. Transformers typically require very little—and receive less—attention than most other electrical apparatus. The required maintenance governed by the size, importance, and location of the system, ambient temperatures, and the surrounding atmosphere.

Alarm and public address equipment. Inherent to most electrical systems at a power generating facility, especially a nuclear power plant, is alarm and public address equipment. This equipment is required to alert employees of plant status, conduct emergency drills, and provide warnings and instructions in case of an accident. Equipment can include sirens, loud speakers, bells, and other types of alarm devices.

2.3.3.4 Conveying Systems

Hydraulic elevators. Hydraulic elevators provide a means of conveyance between building or structure elevations. They use hydraulic power to raise (push up) and lower a cab. Unlike for traction elevators, lift cabling is generally not required. These units are primarily used for service or freight transport because of their level limitations (typically two to six floors), although some small office buildings use them. This system includes the elevator cab, lift cylinder assembly, miscellaneous hoisting apparatus, hydraulic unit (tank, pump, and motor), instrumentation, equipment panels and controls, and related pipe, fittings, instrumentation, and valves.

Traction elevators. Traction elevators provide a means of conveyance between building or structure elevations. They use motor-driven sheaves, cables, and counterweights to raise and lower a cab. Primarily used for passenger service, these units are more sophisticated than hydraulic units, using additional control equipment to provide smoother acceleration and faster transportation. This system includes the elevator cab, cable, counterweight assembly, drive assembly, miscellaneous hoisting apparatus, motor-generator set, and equipment panels and controls.

Escalators. Escalators provide a means of conveyance between building elevations. They use motor-driven sprockets and chains to continuously drive a series of steps in a loop between floors. Primarily used for passenger service, in older buildings, these units are more easily installed than elevators. They are also more "user friendly," avoiding the waiting time and queuing associated with elevators. This system includes a supporting structure, the loop of steps, a handrail assembly, a drive assembly, and equipment panels and controls.

2.3.4 External Systems

For this report, external systems refers to various features—often found near or around a facility—that improve or enhance the usage of the structure. The treatment (in this report) of external systems is limited to personnel/vehicular access (walks, drives, curbs, and asphalt surfaces), drainage control systems, fences, and storage tanks.

2.3.4.1 Walks, Drives, Curbs, and Asphalt Surfaces

Asphalt, as a material, is mostly found as surfaces (pavements) for parking lots, walks, and storage areas. If correctly placed, asphalt is a flexible and durable surface. Like any other type of building material, it should be maintained. In some cases, walks and drives can be constructed with concrete.

2.3.4.2 Runoff, Drainage, and Erosion Control Systems

The important factors involved in drainage are grades or slopes, soil permeability, and vegetative covering. Good drainage is essential for the proper distribution of moisture in the soil and for the control of excessive runoff water. Improper drainage results in wet and dry spots, soil erosion, and possible building damage. Good drainage results in a balanced growth of vegetation, operational safety and efficiency, and protection of capital investment in land and structures.

Types and functions of drainage control systems. Drainage can be classified into two broad categories, surface or subsurface:

- **Surface drainage.** Surface drainage provides for the collection, control, and disposition of water from the land surface as well as large quantities of runoffs from roads, walkways, parking lots, and other paved areas.
- **Subsurface drainage.** Subsurface drainage is the collection and removal of water from locations below the ground surface. Properly designed and maintained, surface drainage should reduce—and in many cases eliminate—the need for special underground facilities.

Classification can be determined by whether the water is on or below the surface of the ground when it is first collected and/or how the storm water is conveyed, depending on the respective collection method.

Drainage and erosion control structures. These structures are often used for the detention, retention, and release of storm water. Frequent inspection and maintenance of drainage systems are required to prevent costly breakdown and repairs. The frequency of these activities, however, varies with the amount and tendency of rainfall and with the adequacy and condition of the drainage facilities. Several common types of drainage and erosion control structures that can be installed at a power generating facility are the following:

- **Open-earth channels.** Open-earth channels serve to intercept or divert and carry surplus water or concentrated surface runoff away from specific ground sites.
- **Vegetated channels.** Vegetative waterways are required as a part of the water disposal system on practically all sloping areas. They are used to reduce gully erosion and to convey runoff. In virgin lands, natural swales and draws lead down hillsides. Many of these are plowed out, and soon after the vegetation is destroyed, they become large gullies.
- **Lined channels.** The function of channel linings is to facilitate and control transportation of water to the point of disposal as rapidly as possible without damage to grounds by loss of soil or water. Linings commonly used are concrete, bituminous materials, brick, stone, and split pipes. The type varies with local conditions, such as soil type and permeability. Weep holds can be installed at the bottom of the lining to prevent uplift from hydrostatic pressure.
- **Bank protection.** Special measures are frequently required for the protection of drainage channels against undercutting and caving. These types of failures result from scour erosion and removal of soil materials from the base of the slope.

- **Dikes and levies.** Dikes and levies are earthen embankments used principally to protect low-lying lands against flooding.
- **Tile drains.** Tile drains remove excess free water from the soil, but do not ordinarily remove water needed by vegetation. Tile drains also establish a better moisture-soil-air relationship for growing vegetation.
- **Check dams.** A check dam, as used in this report, is a small, low dam constructed in a drainage channel or gully to decrease the rate of flow, check scouring erosion, and stabilize the drainageway. Temporary check dams can consist of logs, branches, or loose rock that can be used on gentle slopes while vegetation is being established. Steeper grading and large runoff flows usually require permanent masonry structures.
- **Manholes, inlets, and catch basins.** Manholes, inlets, and catch basins are used together for the collection and disposal of runoff into subsurface pipes. These inlets consist of open-top concrete or masonry box structures fitted with removable covers. This type of structure is commonly used in conjunction with approved ground, roadside, and similar storm drain systems. Their principal function is acceleration of water runoff in low or flat areas where pools of water collect.
- **Culverts and outlet structures.** Culverts and outlet structures are used to control the flow of water discharging from subsurface pipes into a larger area.
- **Tide gate.** Although it is not a common occurrence, some storm drainage lines discharge directly into larger, saltwater bodies. When this occurs, considerable damage can result if proper maintenance precautions are not taken. In most cases, saltwater can be prevented from leaking into natural water courses by the installation of a tide and spill gate. These gates can be installed at the outlet end of open-end ditches, or at the outlet end of culverts that empty into similar locations.
- **Drop spillways.** Properly constructed drop spillways are usually in the form of a straight rectangular weir inlet or a box inlet.
- **Storm sewers.** Storm sewers or drains are used to collect and dispose of surface water through the use of underground structures. A storm sewer usually consists of an underground layer of pipe, box, or arch-shaped structures supplemented by the necessary manholes, inlets, catch basins, and outlet structures.
- **Hillside diversions.** These diversions include terraces, furrows, and diversion ditches. They provide an outlet into natural hillside draws that are well vegetated or into special erosion-free outlet channels that are designed and constructed to receive the runoff and convey it down steep slopes. The outlet channels can be either vegetated waterways or flumes lined with an erosion-resistant material such as concrete.

2.3.4.3 Fences

Fences are of many types and are used for a variety of purposes. Chain-link fences are usually used as security fences, and can be protected on top by barbed wire. Other fences can be made of stranded wire, wood rail or picket, poles, and cables.

2.3.4.4 Tanks

Three major types of storage tanks typically found at a power generation facility or U.S. DOE process facility are the following:

- Aboveground
- Underground
- Elevated

For this report, the tanks are not pressurized and are not considered to be pressure vessels. The types of tanks described in this report (and those typically controlled by the facilities maintenance manager) are typically used for the storage of the following liquids:

- Carbon-based fuels (such as gasoline, kerosene, and diesel oil)
- Chemicals and solvents
- Lubricants

2.4 Advantages and Disadvantages of Various Building Materials

A working knowledge of both the general and structural properties of materials is essential to anyone involved with their maintenance. A brief summary of the advantages and disadvantages of the primary materials used in construction today is presented in Table 2-7.

Table 2-7
Advantages and Disadvantages of Major Building Materials [1]

Material	Advantages	Disadvantages
Aluminum	Lightweight High resistance to corrosion Low electrical resistance Good conductor	Softness Limited strength for structural uses Low stiffness High rate of thermal expansion Low rate of fire resistance Relatively high cost
Concrete	High compressive resistance Durable Resistance to moisture, rot, insects, fire, and wear Low bulk cost Watertight (depending on water-to-cement ratio)	Workability Lack of tensile strength Lack of resistance to many types of chemical exposure, such as salt Hard-to-remove stains

Table 2-7 (cont.)
Advantages and Disadvantages of Major Building Materials [1]

Material	Advantages	Disadvantages
Copper	High resistance to corrosion Good electrical conductivity Workable Forms its own surface protection Thermal contraction and expansion not high	Costly Strength varies with treatment and mechanical working
Epoxy	(Can have varied properties depending on composition) Liquid used very applicable Controllable Excellent strength properties Small creep during curing Hard Tough Resistant to abrasion Resistant to corrosion, salts, acids, petroleum products, solvents, and other chemicals Adhesion to surfaces good	Color Form
Glass	Considerably strong Large sizes are expensive Noncorrosive	Brittle, subject to shattering under shock Transmits energy at a rapid rate
Lead	Good resistance to corrosion	Heavy High coefficient of thermal expansion Difficult to hold in place
Masonry	Available in small units Appearance (available in many textures, stress, and colors) Good insulator	Stains are hard to remove Porous (absorption rate is high) Shrinkage of mortar Thermal and expansion cracking Others (see concrete)
Paper	Readily available Low in cost Used in conjunction with other materials	Susceptible to water damage Susceptible to rot Relatively weak Highly combustible

Table 2-7 (cont.)
Advantages and Disadvantages of Major Building Materials [1]

Material	Advantages	Disadvantages
Plastics: general	Applicable to many uses Relatively low in cost Workable into many shapes High strength Lightweight Noncorrosive	Lack of resistance to fire Low stiffness High rate of thermal expansion Low thermal conductivity Some cases of chemical or physical instability with time Nonsalvageable
Plywood	Stronger than standard lumber Durable High resistance to impact and load Not as affected by moisture changes as standard wood Workability Others (see wood)	Dimensional stability not as good as that of standard structural lumber Poor quality glues are possible Thermal expansion and contraction more of a problem
Steel	Strong Most resistant to aging Most reliable in quality, noncombustible, nonrotting, dimensionally stable with time and moisture change Resistant to staining	Costly Resultant loss of strength when exposed to intense heat, rapid heat gain, and loss Corrosive when exposed to moisture and air or other corrosive conditions
Tin	Extremely workable Very resistant to corrosion	Heavy Loss of strength when exposed to heat
Wood	Readily available Relatively low in cost Simple to work with Available in many shapes and forms Good insulating properties	Paint adhesion changes with moisture content of the wood Combustible Susceptible to rot and insect infestation Soft and easily damaged (porous) Dimensional changes due to changes in temperature and moisture Strength changes with changing moisture content
Zinc	Fairly high resistance to corrosion Form its own protective surface Workable	Brittle

Additional consideration can be given to environmental and regulatory aspects, especially with regard to the various types of metals available for building elements.

3
FAILURE MECHANISMS AND AGING MODES

3.1 Introduction

3.1.1 Types of Loads

The first step in determining whether a structural failure is impending is to recognize the types of loads that are acting on the building element. Loads are applied to a structure in two ways: distributed load or concentrated (point) load.

The distributed load is applied either uniformly or nonuniformly. Most floor loads are uniformly distributed loads. This means (for design purposes) that the same magnitude of load exists everywhere on the floor. This type of load, sometimes called an area load, is given in units of force or weight per unit area (such as pounds per square foot). Nonuniform distributed loads exist in such structures as liquid storage tanks or below-ground foundations such as retaining walls. The units of nondistributed loads are essentially the same as for uniform loads. The only difference is the method of design.

The second way a load is applied is as a concentrated or point load. An example of this is a piece of machinery sitting on a floor member. The units of a concentrated load are measured in weight units such as pounds or kilograms.



Key Technical Point

Loads are applied to a structure or building element in two ways: either as a distributed load or a concentrated (point) load.

3.1.2 Stress and Strain

A structure, and thus the materials making up the structure, react to the applied load by resisting the effect of the external force. In resisting external force action, internal forces called stresses are set up within the material as they resist the attempt of the element to change shape. A stress in a body is an internal resistance to an external force, and can be measured in pounds per square inch.

Internal stresses are always accompanied by deformation of the material, known as strain. *Strain* is defined as the total change in length divided by the total length of the member. The units assigned to strain are inches per inch.

When subject to a load, a structure or structural element twists, curves, stretches, shortens, and/or sags, thus assuming some new configuration as the strains accumulate in an overall shape change of the structure. The visualization of what is actually occurring is important. Some types of deformation can be observed visually, while others can be detected only by using scientific measuring devices depending on such parameters as material size and shape, length between supports, and others.

The type of deformation can be a clue as to the types of stresses that are being produced to cause material deterioration. It is normal for stress and deformations to occur up to a certain limit, depending on the type of material being used. Only a limited amount of stress can be endured before a breakdown (failure) occurs. When an overstressed condition is induced in any material, it reacts by breaking down physically, thus impairing its ability to carry the induced load. Localized deterioration of the material is evidence of the breakdown process taking place.

3.1.3 Tension and Compression



Key Technical Point

Two basic types of forces—tension and compression—(and thus induced stress) cause material deterioration.

Tensile stresses are produced by pulling-type forces, while compressive stresses are produced by pushing- or crushing-type forces. When compression and tension occur simultaneously on a structural element, the result is known as bending. Other types of internal stresses that the structural engineer is concerned about are shear (a type of slicing action) and torsion or twisting.

3.1.4 Types of Stress

Maintenance and inspection personnel must be able to relate the type of deformation and its location on the structural element to the basic type of stress causing it in order to evaluate whether the resulting deterioration is evidence of a potential structural failure.

The basic types of stresses and the resulting types of deformation along with possible resulting deterioration indicators that appear when the member is in an overstressed condition are summarized as follows:

- **Tension (pulling force).** Produces tearing at holes and notches; induces straightening of bent elements.
  - Steel: produces elongation; produces tears in structure
  - Concrete: causes cracking
  - Wood: causes elongation, then splitting
- **Compression (pushing and crushing).** Produces crushing of stocky elements, buckling of slender element; can be transferred by simple contact bearing with no connection as such.
  - Steel: shortening of stocky members (relatively short and large in cross section); buckling of slender members (relatively long and small in cross section)
  - Concrete: crushing, spalling of stocky members; buckling, crushing, and spalling of slender members

- **Shear (slicing action).**
  - Steel: tearing separation; localized buckling at the point of load
  - Concrete: diagonal cracking beginning at point of maximum shear
  - Wood: tearing with cutting separation
- **Bending.** Causes curving, tension, compression, and shear forces in a section. Bending stress causing possible failure is maximum at the outermost fibers of a member, such as the flanges of an open shell member. Buckling is a form of bending.

Table 3-1 summarizes the basic failure mechanisms for major structural materials.

Table 3-1
Summary of Major Structural Material Failure Mechanisms [1]

Material	Tension	Compression	Shear	Torsion	Bending
Structural steel	Necking down	Crushing: short, stocky members Buckling: long, slender members	Local distortion at concentrated loads and supports	Twisting and local buckling	Compression and tension
Reinforced concrete	Cracking (usually without spalling)	Crushing and spalling	Diagonal cracking from support or concentrated loads	Cracking and local crushing	Depends on design; some cracking and no spalling
Wood/ timber	Splitting	Crushing: short, stocky members Buckling: long, slender members	Cutting action (some splintering with plane of wood)	Cracking and splintering	Combination of tension and compression

3.2 Failure Mechanisms of Major Structural Materials

3.2.1 Reinforced Concrete

Table 3-2 lists failure mechanisms for reinforced concrete.

Table 3-2
Failure Mechanisms for Reinforced Concrete [1]

Failure Mechanism	Probable Cause	Symptoms
Alkali-aggregate expansion	• Chemical reaction between aggregate and cement paste	Slight cracking to complete breakup.
Cavitation	• Rapid movement of water or other liquids across the surface	Spalling around projections. Honeycombing. Popping and cracking noises when water moves over the surface.
Cracks (before hardening of the concrete)	• Construction movement, settlement, shrinkage around reinforcement • Setting shrinkage due to inadequate finishing and curing	Random, isolated, or patterned cracks.
Cracks (after hardening of the concrete)	• Chemical reactions such as corrosion • Physical, such as drying shrinkage • Thermal changes (subjected to temperature extremes, such as from freezing and thawing cycles) • Stress concentration • Structural design • Accidents from overload, vibration, fatigue, and earthquake	Patterned cracking, protruding aggregate, popouts. Chemical analysis indicates deterioration of cement paste. Surface cracking, patterned. Extreme change in measured temperatures between inner and outer surfaces. Shallow cracking. Localized cracking. Cracks, usually isolated. Cracks can be isolated or patterned depending on crack-producing agent.
Corrosion of reinforced steel	• Insufficient cover of steel • Quality of concrete • Overuse of calcium chloride as admixture	Cracks occur at the level of the reinforcement and parallel to it. Rusting or discoloration is evident.
Crazing	• Shrinkage on surface more rapid than in interior of concrete mass • Too high a slump • Too rich a mix • Poor timing on finishing • Too rapid absorption of moisture	Shallow cracks forming hexagonal pattern.
Dusting	• Too wet of a concrete mixture • Premature or excessive working of the surface • Organic materials in the aggregate • Inadequate curing	Appearance of a powdery substance on the surface of the concrete.

Table 3-2 (cont.)
Failure Mechanisms for Reinforced Concrete [1]

Failure Mechanism	Probable Cause	Symptoms
Efflorescence	• Water migrating from the interior mass of the concrete to the surface and depositing salts	Appearance of crystalline salts on the concrete surface.
Fire	• Fire	Charred and spalled surfaces.
Form scabbing	• Form oil improperly applied	Difficult to remove forms. Uneven, spalled areas.
Holes (large and small)	• Chemical reaction • Inadequate construction and design	Popouts, holes, random pattern, or isolated in extreme.
Honeycombing	• Placing concrete aggregate with insufficient type of mortar • Improper placing techniques, such as inadequate vibration	Surface defects/voids. Coarse aggregate broken away from the surface.
Popouts	• Breaking away of a particle near the surface • Excessive amount of moisture or temperature changes in the region	Depression left by material popping out. Presence of disintegrated material near the popout.
Sand streaking	• Concrete mixed with a high water content or a deficiency of finer sizes that are placed in a formwork that is not water tight	Vertical streaks of sand that appear on the surface, most noticeable when forms are immediately stripped.
Scaling	• Severe free/thaw conditions • Improper use of deicing salts • Repeated wetting and drying of concrete • Improper finishing • Chemical attack of concrete • Heat blast	Flaking or peeling away of thin layers of concrete.
Spalling	• Corrosion of reinforcement • Mechanical damage • Incorrect form removal • Shock waves	Fragments of concrete that have been broken from the surface. Corrosion of reinforcement.
Stain or uneven color	• Chemical action of foreign materials on the surface • Mixing of different types of cement with each other • Reaction of materials making up the concrete mixture	Discoloration or lacking uniformity in appearance.

3.2.2 Structural Steel

Table 3-3 lists failure mechanisms for structural steel.

Table 3-3
Failure Mechanisms for Structural Steel [1]

Failure Mechanism	Probable Cause	Symptoms
Abrasion	• Members subjected to contact with moving parts • Members subjected to wave action • Members immersed in a moving liquid	Worn, smooth appearance, general depression of the abraded area.
Corrosion	• Chemical or electrochemical reaction that converts the metal into an oxide, carbonate, and sulfides	Pitted, oxidized surface showing loose flakes; reddish-brown rust colored appearance.
Fatigue	• Repetitive, cyclic loading occurring at stresses at or below allowable design values	Small fractures oriented perpendicular to the line of stress.
Impact	• Human error, wind, and gravity	Local distortion of the member in the form of a sharp crimp. Occurs in a tension member of flange.
Lamellar tearing	• Incorrect welding process	Minute, often unseen cracking in the weld. Might need microscopic instruments to observe.
Loosening of connections	• Impact and fatigue loading	Vibrations, improper tightness, or loss of connections.

3.2.3 Wood/Timber

The major causes of wood deterioration are decay-causing fungi, marine borers, insects, and fire damage. The types of problems inherent in wood that require eventual maintenance are excessive deflection, checking, splitting due to shrinkage of the timber, and deterioration of the hardware. Table 3-4 lists failure mechanisms for wood/timber members.

Table 3-4
Failure Mechanisms for Wood/Timber Members [1]

Failure Mechanism	Probable Cause	Symptoms
Excessive splitting and checking	• Excessive relative amount of members at a joint	Longitudinal separation along the grain of the wood.
	• Bowing of compression members	Broken paint lines or newly exposed wood. Elongated bolt holes.
Decay (rot)	• Insect infestation (carpenter ants, beetles, carpenter bees, and termites)	One or more shelter tubes, wood that collapses easily when probed with an ice pick or a pocket knife or tapped with a hammer.
	• Fungi	Softening and discoloration of wood, fluffy or cottony appearance, destruction of wood cells, appearance of fruity bodies in the form of mushrooms; incrustation in the advanced stage.
	• Marine borers	Minute openings in the timber, hollow sound when struck with a hammer, a myriad of surface grooves, narrowing of a section giving it an hourglass appearance.
	• Moisture/exposure to extreme weather conditions	Discoloration, warping, disintegration of wood fibers.
Charring	• Fire damage	Surface cellular damage, charred surfaces, easily probed with a knife.

Because wood is a natural building material, it typically contains various types of imperfections that can affect its strength in a given application. Table 3-5 describes these types of common imperfections and their effects on grading structural lumber.

Table 3-5
Common Imperfections in Wood/Timber [1]

Imperfection	Description	Effects on Strength	Effect on Grading Structural Lumber
Checks and splits	Split in the wood	In lumber subjected to bending, checks and splits reduce the resistance to shear; they do not affect the strength for longitudinal compression.	Checks and splits are restricted in those parts of a bending member where shearing stresses are highest.
Holes and knots	A knothole or a hole caused by some other means, or localized imperfections	Reduce tensile strength, somewhat more than compressive and shear strength, and affect stiffness.	The size, number, and location of knots is restricted for structural lumber; cluster knots are prohibited.
Pitch pockets	Opening between growth rings containing pitch or bark	Little or no effect.	Usually disregarded except if a large number occur; shake can be present, or bond between annual growth rings can be weakened.
Shakes	A separation of the wood between the annual growth rings	In lumber subjected to bending, shakes reduce the resistance to shear; they do not affect the strength for longitudinal compression.	Shakes are restricted in those parts of a bending member where shearing stresses are highest.
Slope of grain	Areas where the direction of the wood grain is not parallel to the edges of the piece of lumber	Twist with changes in moisture content.	Cross-grained pieces are undesirable; reduction of strength due to cross grain in structure is taken as twice the reduction observed in tests of small, clear specimens.
Wane	Bark or lack of wood on the edge or corner of the piece of lumber	Affects nailing and bearing.	Limited in structural lumber requirements for fabrication, bearing, nailing, and appearance, and not for its effect on strength.

Different types of wood have varying degrees of resistance to decay and rot, and they are described in Table 3-6.

Table 3-6
Decay Resistance of Major Woods [1]

Wood Type	High	Moderate	Low
Alder			X
Ash			X
Aspen			X
Bald Cypress		X	
Basswood			X
Beech			X
Birch			X
Buckeye			X
Butternut			X
Catalpa	X		
Cedar	X		
Cherry, Black	X		
Chestnut	X		
Cottonwood			X
Cyprus, Arizona	X		
Douglas Fir		X	
Elm			X
Hackberry			X
Hemlock			X
Hickory			X
Honey Locust		X	
Juniper	X		
Larch, Western		X	
Locust, Black	X		
Magnolia			X
Maple			X

Wood Type	High	Moderate	Low
Mesquite	X		
Mulberry, Red	X		
Oak, Bur	X		
Oak, Chestnut	X		
Oak, Gambel	X		
Oak, Oregon White	X		
Oak, Post	X		
Oak, Red and Black			X
Oak, Swamp Chestnut		X	
Oak, White	X		
Osage Orange	X		
Pine, Eastern White		X	
Pine, Longleaf		X	
Pine, Slash		X	
Pine, Others			X
Poplar			X
Redwood	X		
Sassafras	X		
Spruce			X
Sweet Gum			X
Sycamore			X
Tamarack		X	
Walnut, Black	X		
Willow			X
Yew, Pacific	X		
Yellow Poplar			X

3.3 Failure Mechanisms of Facility Finish Materials

3.3.1 Exterior Materials

3.3.1.1 Wood Exteriors

Wood exteriors are susceptible to the same types of failure mechanisms that are noted for wood/timber structural members. The main causes of wood exterior failures are moisture, inferior workmanship and materials, and structural failure.

3.3.1.2 Metal Exteriors

The primary failure mechanisms for metal exterior surfaces are corrosion, physical deformation from impact or wind shear, and tearing.

3.3.1.3 Masonry and Concrete Exteriors

These exterior surfaces typically require less frequent maintenance than most outside materials, but failures can occur. For example, leakage through concrete walls is caused by cracks in the concrete and, in rare cases, porosity of the concrete. The cracks can be caused by foundation settlement, excessive floor loadings, temperature expansion and contraction in structural members, or poor materials/workmanship in the original construction.

Common defects in brick walls include open vertical joints, cracking, spalling, and porosity. Efflorescence and leakage of rainwater through the walls usually result from such defects. Inadequate or improperly design and constructed flashings also cause serious leakage. Open vertical joints result from failure to fill the joints with mortar in laying the brick. Cracking can result from settlement, expansion and contraction, misalignment, or some other serious structural defect in the building. Spalling results if bricks are soft or if they tend to powder or crack, or when moisture freezes within the masonry. Porosity in brick walls is rare and can result only from the use of porous brick or mortar. Mortar containing large aggregate or poor quality brick can produce this porous condition.

3.3.1.4 Mineral-Surfaced Board Exteriors

The most common failure mechanisms of these exterior finish products are decomposition, loss of physical properties, and swelling, which are all caused by water/moisture penetration.

3.3.2 Interior Ceiling and Wall Materials

The most frequent maintenance problems with plastered and gypsum board surfaces are cracks, holes, loose segments, and water stains. Cracks, holes, and looseness in plastered surfaces are signs of excessive internal or external stresses. Defects can be caused by poor workmanship, such

as improper proportions or application of the plaster, imperfect lathing, and poor atmospheric conditions during plastering; by moisture infiltration or an excess of moist air generated inside a building; or by settling or other movement of some part of the building frame. Moisture causes spalling, efflorescence, and stains. External stresses that cause plaster damage should be investigated and corrected before repairs are made to the plastered surfaces themselves. Other causes for defects are the following:

- Settlement of the structure
- Defective materials
- Operational abuse
- Inadequate protection from environmental attack
- Inadequate maintenance procedures
- Incomplete engineering or design
- Vibrations
- Structural expansion and shrinkage
- Wind pressures
- Lack of proper inspection and supervision

Table 3-7 provides a listing of common failure mechanisms and symptoms of failure for various interior building materials.

Table 3-7
Common Failure Mechanisms and Symptoms for Various Interior Building Materials [1]

Wall Material	Failure Mechanism and Symptoms
Acoustical tile	Staining, cracking, discoloration, permanent bending, swelling, and warping.
Brick or block	Cracks, staining, loose mortar, and missing bricks/blocks.
Corrugated plastic sheeting	Cracks, fading, and chipping around the edges.
Glass blocks	Cracks and loose mortar.
Plaster: bare	Loose plaster: bulging and cracking of large areas of the surface. Map cracks: penetrate through the plaster, but do not extend entirely across the surface. Generally occur as a series of irregular cracks running at various angles. Shrinkage cracks: resemble map cracks. Confined to the finish coat. Do not extend entirely through the plaster surface. Covers a much smaller portion of the wall or ceiling surface. Structural cracks: large, well-defined cracks. Extend across the surface and entirely through the plaster. Develop during the first year in the life of a building. Can extend diagonally from the corners of door and window openings, run vertically in corners where walls join, run horizontally along the junction of walls and ceilings, or occur in walls where two unlike materials join.
Plastic blocks	Cracks, loose mortar, and discoloration.
Stone and artificial stone	Cracks, staining, loose mortar, and missing bricks/blocks.
Wallboards and plasterboards	Cracks, staining, swelling, warping, loose nails/screws, holes, dents, and cracks at joints.
Wood	Excessive splitting and checking, decay (rot), and charring.

3.3.3 Floors

The major causes of deterioration of flooring materials are the following:

- Moisture
- Settlement
- Shrinkage
- Structural defects
- Inadequate materials
- Inadequate installation
- Chemical attack: environment exposure

- Operational abuse
- Poor construction details

Common failure mechanisms of flooring materials are listed in Table 3-8.

Table 3-8
Common Failure Mechanisms for Flooring Materials [1]

Flooring Type	Cracking	Deterioration	Disintegration	Fading	Discoloration	Staining
Resilient	Cuts Scratches Pitting Tears	Bleeding Holes Roughness Shrinkage Swelling	Powdering Softening Stick	X	Whitening Black marks Darkening	Uneven gloss Rapid soiling
Wood	Splits	Decay	Rot			X
Carpet			Rot	X	X	X
Formed in place	X				X	X
Masonry	X		Powdering			

3.3.4 Roofs

In most cases, roof failures are the result of faulty design, workmanship, or simply the lack of routine inspections and maintenance. Most failures are premature. Few roof installations, especially field-fabricated membrane types, last the expected life of 15 to 20 years without some failure requiring repair or replacement.

In order to inspect a roofing system and select the correct repair procedures, the major types of and reasons for roof failure and the most effective maintenance and repair procedures should be identified and understood.

Key Technical Point

The most common types of roof failure are splits in the roofing, moisture impregnation, improper drainage, and material degradation or deterioration.

Depending on the type of roof, certain types of failures are more common, as shown in Table 3-9.

Table 3-9
Failure Mechanisms for Various Types of Roofs [1]

Type of Roof	Common Failure Mechanisms
Built-up	Bare areas Weathering Exposed felt Cracked roof member Large blisters or buckles Fishmouths (buckled open end laps)
Asphalt shingle	Loose shingles Hail-damaged shingles
Asphalt rolled	Cracks at seams, causing leaks
Asphalt cement	Broken shingles Fastener deterioration
Metal	Broken soldered seams Excessive corrosion
Slate	Weathering and slate failure Broken tiles
Wood shingle	Warping and splitting of shingles Weathering and deterioration Loose fasteners
Single membrane	Cracks Blisters or buckled edges

Some of the reasons for these common roof failures are the following:

- Failure of roofing structure
- Temperature and moisture interaction
- Improperly mounted objects on or through the roof
- Incompatibility of construction materials and thermal effects
- Improper patching and reroofing
- Inadequate inspections
- Inadequate testing of roofing materials
- Inadequate or improper specifications

- Reverse shingling or flashing material
- Improper selection or mixture of materials in the system
- Use of asphalt for flat roofs
- Use of tar and tar-based cements for steep roofs
- Bleeding of pitch at eaves and into roof drains and at projections through the roof
- Installation of wet components
- Weather (such as wind damage, hail damage, and impact damage from fallen tree limbs)
- Overheated bitumen
- Cold bitumen
- Long exposure of felts before application of gravel
- Too little gravel
- Use of vapor barrier or base sheet as a temporary roof
- Water behind flashing sections
- No ventilation of insulation
- Improper use of vapor barrier
- High roof drains
- Lack of maintenance
- Use of unseasoned or untreated lumber

3.3.5 Windows and Doors



Key Technical Point

Typical failure mechanisms for windows include surface (frame) disintegration, swelling and warping of the frame (causing binding or loss of seal), loose or broken hardware, corrosion or rusting of metal frames and hardware, deteriorated or disintegrated weather stripping, or broken glass.

Typical failure mechanisms for doors include the following:

- Shrinkage of the door
- Warping
- Sagging
- Rattling
- Loosening of hinges
- Settling of the door frame

- Inability to latch and/or lock
- Sticking
- Corrosion or rusting of metal door components and hardware

3.3.6 Coatings for Exterior Surfaces

Paints are not indestructible. Even properly selected protective coatings, properly applied on well-prepared surfaces, gradually deteriorate and eventually fail. The rate of deterioration under such conditions, however, is slower when proper painting operations are carried out.

3.3.6.1 Exterior Deterioration



Key Technical Point

Paints that are exposed to the external environment normally proceed through two stages of deterioration: generally, a change in appearance followed by gradual degradation.

If repainting is not done in time, disintegration of the paint takes place, ultimately followed by deterioration of the substrate (natural surface).

Change in appearance. The first stage of deterioration appears as a change in appearance of the coating, with no significant effect on its protective qualities. This change in appearance can result in any one or a combination of the following, depending on the type and color of the paint used and the conditions of exposure:

- **Soiling.** Exterior coating normally gathers dirt and becomes increasingly soiled.
- **Color changes.** Many colors, especially the brighter ones, fade and turn duller with time. Tinted paints become paler. Enamel and latex paints fade less rapidly than the softer linseed oil paints. Whites, especially those based on linseed oil, yellow in areas not protected from the sunlight.
- **Flatting.** Glossy paints lose their gloss and eventually turn flat with age. This is a sign of initial breakdown. Loss of gloss is soon followed by chalking. Enamels flatten (and chalk) less rapidly than the softer linseed oil paints.

Degradation. The second stage in normal deterioration occurs after continued exposure. The coating begins to break down, first at the surface, then, unless repainted, gradually through the coating and down through the substrate. Two types of degradation, chalking and checking (or cracking), take place. The degree of either depends on the type of paint and the severity of exposure. These types of degradation are described as:

- **Chalking.** Chalking is the result of weathering of the paint at the surface of the coating. The paint is broken down by sunlight and other destructive influences, leaving behind loose powdery pigment, which can easily be rubbed off with the finger. Chalking takes place more rapidly with softer paints and is most rapid in areas exposed to large amounts of sunshine.

Chalking can be an asset, especially in white paints, because it is a self-cleaning process. Chalked paints are also generally easier to repaint, because the underlying paint is in good condition and, generally, little surface preparation is needed.

- **Checking and cracking.** Checking and cracking are breaks in the paint film, which are formed as the paint becomes hard and brittle. Temperature changes cause the overlying paint to expand and contract. As the paint becomes hard, it gradually loses its ability to expand without some extent of breaking. Checking is characterized by tiny breaks that appear only in the upper coat or coats of the paint film without penetrating the substrate. The pattern usually resembles a crow's foot. Cracking appears in the form of larger and longer breaks that extend through to the substrate. Cracking generally takes place to a greater extent on wood than on other substrates because of wood's grain. Checking and cracking are aggravated by excessively thick coatings of paint because of their reduced elasticity.

3.3.6.2 Disintegration

As the coating degrades, it finally reaches the point of disintegration. Several types of disintegration are possible:

- **Erosion.** As chalking continues, the entire coating wears away (erodes) and becomes thinner. Eventually, it becomes too thin to hide the substrate.
- **Crumbling.** If the cracks are relatively small, the moisture penetrating through the coating causes small pieces of the coating to lose adhesion and fall off the substrate.
- **Flaking and peeling.** Moisture goes into the cracks and loosens relatively large areas of the coating. The paint then curls slightly, exposing more of the substrate and it finally flakes off. Peeling is an aggravated form of flaking in which large strips of paint can be easily removed.

3.3.6.3 Complete Deterioration

When large areas of substrate become exposed, the coating has reached the point of complete deterioration and is in a state of neglect. Such surfaces require extensive and difficult preparation before repainting. All of the old coating may have to be removed to be sure that it does not create problems by continuing to lose adhesion and taking the new coating with it. Furthermore, complete priming of the exposed substrate is often required, thus adding to the cost and time. Continued neglect can also lead to deterioration of the structure, resulting in expensive repairs in addition to painting costs.

3.4 Failure Mechanisms of Facility Systems

3.4.1 Water Distribution Systems

3.4.1.1 Fresh and Waste Water Plumbing Systems

Exposed piping. Failure mechanisms for exposed piping include corrosion, loose connections, defective caulked joints on bell and spigot pipe, loose bolts on flanged pipe and clamp-type connections, and damage to protective coatings. These failures could lead to either leakage or restriction of flow.

Underground piping. Failure mechanisms for underground piping include erosion of pipe lining, corrosion of pipe inner and outer surfaces, and structural failure. These failures could lead to either leakage or restriction of flow.

Fixtures. Failure mechanisms of fixtures in a fresh or waste water system can include the following:

- **Water closets.** Moisture on the floor at the base of the water closet usually indicates that the seal or gasket between the closet and its outlet has failed. It can, however, also result from condensation on the tank or piping or from leakage of the tank, flush valve, or piping.
- **Water closet tanks.** Water continuously running into the closet after the toilet has been flushed usually indicates that the supply valve is leaking or that the runner tank ball is not seating properly. The lift wire may be bent, or the ball may be worn out or misshaped and, thus, fails to drop tightly into the hollow seat.
- **Flush valves.** Flush valves (for water closets, urinals, and other fixtures) usually fail in operation through clogging of the bypass orifice, wear of the valve seats, and/or failure of the diaphragm or piston packing. The primary symptom is continuous leaking through the valves.
- **Shower heads.** Shower heads fail by clogging that is caused by corrosion or a buildup of mineral deposits. This can result in restricted flow or a supply of water having an uneven or distorted stream.
- **Lavatories, wash fountains, and service sinks.** Drain stoppages usually result from obstructions in the trap or in the line beyond the trap.

Valves and faucets. Valves control the flow of fluid in pipes. Valve failures, which prevent the control of fluid flow, include the following:

- Broken, corroded, or cracked internal parts
- Broken, corroded, or distorted springs
- Failed seating mechanisms resulting in excessive leakage through the valve
- Worn seals/gaskets resulting in excessive leakage to the atmosphere
- Worn, broken, or corroded internal valve mechanisms resulting in sticking and jamming

Continual turning on and off of the faucet wears the washer on the stem, thus causing the faucet to drip.

Pumps. Pump casings cause problems when corrosion or incompatible materials are handled in the pump. Pump casings should be designed of materials that are corrosion resistant. The problems encountered with pump impellers are corrosion, abrasions, and physical damage. Vertical turbine pump failure mechanisms are, in general, similar to those of centrifugal pumps.

Impellers of rotary pumps are subjected to very little corrosion by abrasive materials, and impeller wear is caused mostly by the fluids being pumped. The major maintenance problems with rotary pumps are in the bearings and seals. The major maintenance problems of reciprocating-type rotary pumps focus on the packing glands or seals of the connecting rod and the piston ring. Worn piston rings or packing are quickly indicated by the lack of fluid pressure while the pump is running.

Table 3-10 lists types of failure mechanisms for different styles of pumps that can be included in a facilities maintenance program at a power generating facility, as described in EPRI report TR-114612, *Pump Troubleshooting, Volume 2* [5].

Table 3-10
Typical Pump Failure Mechanisms

Style of Pump	Failure Mechanisms
Vertical pump	Worn casing or impeller wear rings Foreign material in inlet bell, impeller, casing vanes, and/or discharge head nozzle Mechanical defects (damaged impeller, failed/sheared impeller or coupling keys, broken or bent shaft, or failed coupling) Improper impeller lift or worn vanes or case Motor binding Worn packing or packing that is too tight or improperly seated Worn shaft sleeve or seal components Pump imbalance Shaft misalignment Bearing failure or seizure
Horizontal pump	Foreign material in suction line or discharge line Material buildup or clogged passageways Broken or bent shaft Impeller key sheared or missing from assembly Impeller damaged Worn, locked, mismatched, or damaged coupling Shaft misalignment Improperly balanced drum Worn packing or packing that is too tight or improperly seated

Table 3-10 (cont.)
Typical Pump Failure Mechanisms

Style of Pump	Failure Mechanisms
Positive displacement	Packing that is too tight Water intrusion into the crankcase Worn packing or lip seals Broken or missing deflectors Scored plunger shaft Obstructed vent plug/crankcase breather Loose fasteners Worn connecting rod seals and piston rings

3.4.1.2 Fire Protection Systems

Guidance regarding failure mechanisms of fire protection system components is provided in EPRI report 1006756, *Fire Protection Equipment and Surveillance Optimization and Maintenance Guide* [4].

3.4.2 Heating, Ventilating, and Air Conditioning Systems

3.4.2.1 Facility and Building Ventilating and Exhaust Air Systems

In general terms, the primary failure mechanisms of these types of systems are system imbalance, which can be loss of air flow or irregular air pressure, and irregular air temperature and humidity levels. However, these conditions can be a result of many different types of failures of the components of the system. Table 3-11 lists ventilating and exhaust air system failure mechanisms that can result in degraded system performance.

Table 3-11
Ventilating and Exhaust Air System Failure Mechanisms [1]

System Component	Failure Mechanisms
Ducts, collectors, smoke pipes, and hoods	Abrasion of linings and inner surfaces Physical deformation Collection of soot, dirt, or grease, which restrict flow Cracks and loss of seal at seams/joints Loose connections Loss of structural integrity of duct supports
Motors, drive assemblies, and fans	Dust, dirt, and other accumulation Loose, missing, or damaged connectors Bent blades Worn or loose belts Unbalance or misalignment Excessive noise and/or vibration Corrosion of metallic parts Coupling and/or bearing failure
Wiring and electrical controls	Loose connections Charred, frayed, broken, or wet insulation Short circuits Loose or weakened contact springs Worn, pitted, or corroded connections
Steam and hot-water coils	Flow restriction and clogging Rust and corrosion Cracking resulting in leaks Loose connections and parts Physical deformation and bent fins Water hammer Defective or inoperable valves
Thermal insulation and protective coverings	Open seams, breaks, or missing sections Missing or loose fastening Material disintegration and loss of insulating capability
Baffles, dampers, vanes, access doors, registers, louvers, and screens	Clogging with dirt, dust, or grease Broken, loose, or missing connections Corrosion of metallic parts Degradation of nonmetallic seals Physical deformation: bent louvers or vanes
Air filters	Flow restriction from dust, grease, or other deposits Corrosion of metallic parts Physical deformation and bending
Guards, casings, hangers, supports, platforms, and mounting	Loose, broken, or missing parts Physical deformation Corrosion of metallic parts

3.4.2.2 Building Heating Systems

Table 3-12 lists building heating systems failure mechanisms that can result in degraded system performance.

Table 3-12
Building Heating Systems Failure Mechanisms [1]

System Component	Failure Mechanisms
Motors, drive assemblies, fans, and pumps	Dust, dirt, and other accumulation Loose, missing, or damaged connectors Bent blades Worn or loose belts Unbalance or misalignment Excessive noise and/or vibration Corrosion of metallic parts Coupling and/or bearing failure
Wiring and electrical controls	Loose connections Charred, frayed, broken, or wet insulation Short circuits Loose or weakened contact springs Worn, pitted, or corroded connections
Steam and hot-water heating equipment	Flow restriction, scale, and clogging Rust and corrosion Cracking resulting in leaks Loose connections and parts Physical deformation and bent fins Water hammer Defective or inoperable valves
Thermal insulation and protective coverings	Open seams, breaks, and missing sections Missing or loose fastening Material disintegration and loss of insulating capability
Grills, dampers, draft diverters, plenum chambers, registers, and supply and return ducts	Clogging with dirt, dust, and grease Broken, loose, or missing connections Corrosion of metallic parts Degradation of nonmetallic seals Physical deformation: bent louvers or vanes
Air filters	Flow restriction from dust, grease, or other deposits Corrosion of metallic parts Physical deformation and bending
Guards, casings, hangers, supports, platforms, and mounting	Loose, broken, or missing parts Physical deformation Corrosion of metallic parts
Thermostats and automatic temperature controls	Worn or broken mechanical parts Defective temperature-sensing device

Table 3-12 (cont.)
Building Heating Systems Failure Mechanisms [1]

System Component	Failure Mechanisms
Burner assemblies	Loose, damaged, or missing connections and parts Clogged jets, orifices, valves, and fuel supply lines Dirty wicks, oil rings, oil pots, or oil filters Corroded or dirty heat transfer surfaces Nonuniform flame or heat spread
Combustion chambers and smoke pipes	Soot, dirt, and coal deposits, which restrict flow Abrasion and wear Physical deformation Broken, loose, or missing parts Cracks, loss of seal at seams
Traps	Cracks and leakage Physical deformation
Humidifier assemblies	Dust and dirt accumulation Cracked pans causing leaks Clogging of piping Corrosion of metallic parts Contamination of water with mineral deposits and/or microbiological organisms

3.4.2.3 Pneumatic Systems

Table 3-13 lists pneumatic systems failure mechanisms that can result in degraded system performance.

Table 3-13
Pneumatic Systems Failure Mechanisms [1]

System Component	Failure Mechanisms
Reciprocating air compressors	Clogged air filters Worn piston rings Loss of pressure boundary and leakage to atmosphere Inoperable receiver relief valve: broken unloading valve plunger spring, ruptured diaphragm, plugged filter Plugged or clogged intercooler core
Rotary air compressors	Clogged inlet air filter Scaled or corroded water jacket Swelled or warped rotor blades Clogged or dirty unloading valve Worn bearings Worn blades and cylinders Misalignment
Air dryers	Contamination of the desiccant bed Cracking resulting in air or steam leaks Corrosion or rusting of drying tower, piping, and valves

3.4.2.4 Air Conditioning Systems

Table 3-14 lists air conditioning systems failure mechanisms that can result in degraded system performance.

Table 3-14
Air Conditioning Systems Failure Mechanisms [1]

System Component	Failure Mechanisms
Compressors	Clogged air filters Worn piston rings Loss of pressure boundary and leakage to atmosphere Inoperable receiver relief valve: broken unloading valve plunger spring, ruptured diaphragm, plugged filter Plugged or clogged intercooler core
Air ducts, dampers, registers, grills, louvers, and screens	Physical deformation Collection of soot, dirt, or grease, which restrict flow Cracks and loss of seal at seams/joints Loose connections Loss of structural integrity of duct supports
Motors, drive assemblies, and fans	Dust, dirt, and other accumulation Loose, missing, or damaged connectors Bent blades Worn or loose belts Unbalance or misalignment Excessive noise and/or vibration Corrosion of metallic parts Coupling and/or bearing failure
Wiring and electrical controls	Loose connections Charred, frayed, broken, or wet insulation Short circuits Loose or weaken contact springs Worn, pitted, or corroded connections
Steam and hot-water heating units	Flow restriction and clogging Rust and corrosion Cracking resulting in leaks Loose connections and parts Physical deformation and bent fins Water hammer Defective or inoperable valves
Thermal insulation and vapor barriers	Open seams, breaks, missing sections Missing or loose fastening Material disintegration and loss of insulating capability
Air filters	Flow restriction from dust, grease, or other deposits Corrosion of metallic parts Physical deformation and bending

Table 3-14 (cont.)
Air Conditioning Systems Failure Mechanisms [1]

System Component	Failure Mechanisms
Guards, casings, hangers, supports, platforms, and mounting	Loose, broken, or missing parts Physical deformation Corrosion of metallic parts
Temperature and humidity controls	Loose connections Worn, dirty, pitted, or misaligned contacts Inaccuracy of thermostat and humidistats
Electrical heating units	Burned, pitted, or dirty electrical contacts Short circuits Dirty or corroded reflective, heat-transfer surfaces
Pump units	Accumulation of dust, dirt, and other deposits Corrosion of metallic parts Worn impeller and blades Shaft deformation or misalignment Cracks in casing
Piping	Cracks and corrosion Clogging and scaling causing flow restriction
Water sprays and weirs	External scale and corrosion Cracks resulting in leaks Clogging of pipes and nozzles Improperly positioned spray nozzles, baffles, or eliminators to control spray drift Corrosion of metallic parts
Shell- and tube-type condensers	Cracks and corrosion of tubes Clogging and scaling of tubes and shell
Cooling coils	Cracks in coils resulting in loss of refrigerant Bent fins and other physical deformation Clogging and scaling of tube interior restricting flow Corrosion or accumulation of dirt on fins

3.4.3 Electrical Systems

3.4.3.1 Electrical Distribution Systems

Table 3-15 describes failure mechanisms for various components typically used in electrical distribution systems.

Table 3-15
Failure Mechanisms of Components in Electrical Distribution Systems [1]

System Component	Failure Mechanisms
Wiring	Corrosion, fracture, and deterioration of insulation (cracking, disintegration, and hardening)
Ducts and trays	Physical deformation, corrosion, and leakage
Fuses	Corrosion, physical damage, fracture, charring, insulation, and fracture
Circuit breakers	Chatter, inadvertent change of state, open circuit, short circuit, arcing, and physical damage/deformation
Switchgear	Oxidation or corrosion of metallic parts, misalignment of blades and jaws, loose or missing parts, fracture of nonmetallic parts, and binding
Cabinets	Physical deformation and corrosion

3.4.3.2 Lighting Systems

Table 3-16 describes failure mechanisms and their causes for incandescent, fluorescent, and mercury types of lighting equipment.

Table 3-16
Failure Mechanisms of Lighting Equipment and Their Causes [1]

Failure Mechanisms	Probable Causes
Incandescent Lamp Equipment	
Lamp not burning	Lamp loose, burned out, and loose or broken connections
Lamp burns dim	Low voltage
Short lamp life	High voltage, mechanical damage, incorrect lamp, and excessive vibration
Lamp breakage	Water contacting bulb and physical damage
Fluorescent Lamp Equipment	
Lamp fails to start or flashes on and off	Lamp pins not contacting, lamp at end of life, defective starter, low line voltage, fault in circuit of luminaire, and low temperature of surrounding air
Lamp flickers, swirls, or flutters	Cold or too-rapid starting
Ends of lamp glow	Poor ballast, faulty starter, and improper wiring or ground
Lamp darkens early in life	Improper starting, low line voltage, and poor lamp holder contact
Noise from ballast	Improper installation, line feedback, and poor ballast
Mercury Lamp Equipment	
Lamp fails to start	Lamp loose, lamp burned out, low voltage, wiring fault, low temperature, and fluctuating voltage
Lamp frequently goes out	Wiring fault
Cyclic flickering	Improper supply connections and inadequate incandescent luminaires in the system

3.4.3.3 Motors

Motor failures are caused by loading, age, vibration, contamination, or commutation problems. An overloaded motor fails earlier in its expected lifetime than one that is not overloaded. Failures due to age can be delayed by thorough periodic cleaning; dipping and baking the windings; replacing fast-wearing bearings and brushes; and by tightening, turning, and overcutting commutators on dc motors. Failures due to vibrations can be in the form of sprung or broken shafts, bearing or seal failures, insulation breakdown, or broken electrical connections. Vibration can also result in damage to the motor's mechanical structure, broken brushes, and a variety of commutator or slip ring problems.

The vibration itself can be caused by misalignment, bearing problems, or imbalance. Problems with bearings stem from contamination, lack of lubrication, improper fits (either internal or external), overloading, stray electric current, slip ring damage, and vibration itself.



Key Technical Point

The most common cause of motor failure is contamination.

Dirt coats motor windings and cuts down on heat dissipation or blocks ventilation passages and increases insulation temperatures so that failure ultimately occurs. Dirt also causes wear in moving parts, especially bearings. Moisture in combination with dirt also causes insulation failure by shorting the windings or shorting to ground, causing rust.

Commutation problems for dc motors (that is, problems with commutators and brushes) are evident in such conditions as rapid brush wear, chipped or broken brushes, burned brushes, copper feathering or drag, commutator burning, or slot or pitch patterns that are overfilming.

3.4.3.4 Batteries

Batteries can fail due to overcharging or undercharging, improper water level, corrosion, clogged vent plugs, physical damage to terminals and/or battery casing, and leakage.

3.4.3.5 Transformers

Transformers fail due to external damage to brushings and leads, improper level of or contaminated liquid, and leakage.

3.4.3.6 Alarm and Public Address Systems

Failures of this type of equipment can generally be categorized as electrical and mechanical. Electrical types of failures include short circuits and loss of circuit integrity. Mechanical types of failure vary depending on the configuration of the equipment, but typically include physical damage, deformation, and corrosion of subcomponents that render the equipment inoperable. Each product manufacturer's literature should be consulted for additional failure mechanisms regarding each particular piece of equipment.

3.4.4 Conveying Systems

3.4.4.1 Hydraulic Elevators

Probable failure points for hydraulic elevators include the following:

- Severe cab damage due to normal wear and tear and vandalism
- Leakage in cylinder or piping due to corrosion or seal wear
- Pump or motor burnout due to overloading

3.4.4.2 Traction Elevators

Probable failure points for traction elevators include the following:

- Severe cab damage due to normal wear and tear, vandalism
- Excessive cabling wear due to improper lubrication, poor maintenance
- Motor burnout due to overloading

3.4.4.3 Escalators

Probable failure points for escalators include the following:

- Severe step or structure damage due to normal wear and tear, vandalism
- Excessive chain wear due to improper lubrication, poor maintenance
- Motor burnout due to overloading

3.5 Failure Mechanisms of External Systems

3.5.1 Walks, Drives, Curbs, and Asphalt Surfaces

Outside forces that cause deterioration of asphalt are temperature changes, moisture, superimposed loads, and movement of underlying earth. Table 3-17 lists failure mechanisms resulting from these causes.

Table 3-17
Asphalt Failure Mechanisms and Symptoms of Deterioration [1]

Failure Mechanism/Deterioration	Symptom
Alligator cracks	Crack appearing as spider webs.
Bleeding and softening	Soft surface areas.
Chuckholes	Break in the surface extending into the sub-base.
Depressions	Holes.
Edge breaking	Edge of pavement breaking off.
Long cracks	Long cracks in surface.
Numerous wide cracks	Cracking.
Raveled surfaces	Loss of bitumin shows exposed aggregate overlay.
Softening	Surface is soft and spongy.
Weathering of the surface	Surface is gray in appearance and aggregate is bleached out.

3.5.2 Runoff, Drainage, and Erosion Control Systems

Erosion can be caused by natural agents such as wind and water or can result from human activities. Chief sources of erosion from human activities are uncontrolled pedestrians and vehicular traffic.

3.5.2.1 Wind Erosion

Wind erosion is most often prevalent in hot, dry areas where the ground surface is usually dry in summer or winter and protective vegetation is limited or totally lacking. The minimum wind that is required to start the movement of soil particles depends on the size and the weight of the particles. Generally, a velocity of only 8 or 9 mph is required.

3.5.2.2 Water Erosion

Water erosion can result from the impact of individual raindrops or from the uncontrolled flow of water down a slope. Splash and scour erosion can result separately or simultaneously. At the upper end of a watershed, splash is the main cause of erosion, while in a valley channel, most erosion results from scour.

The immediate effect of erosion is the loss of weathered topsoil containing valuable organic matter and plant food elements, and subsequently causing channels and gullies that damage surface structures. Consequently, erosion control practices should be designed to prevent damage as well as correct it.

3.5.2.3 Failure Mechanisms of Drainage and Erosion Control Structures

The most common failure mechanism of these types of structures is mechanical failure resulting in cracking, erosion, and general loss of structural integrity.

3.5.3 Fences

The most common failure mechanisms of fences include corrosion and physical failure (tearing, bending, and deformation) of the fence components. Vines, weeds, high grass, and shrubs should not be permitted to grow up and around fences because moisture retained by the vegetation accelerates rust or rotting of fencing materials. Vegetation—when dry—becomes a fire hazard, which can cause considerable damage to, or loss of, wood fences and fence posts. Fences can also become damaged during periods of high winds, which can cause trees and other debris to physically damage the fence.

Erosion around fences often defeats the purpose for which the fence was intended. Earth that is washed out under the fence leaves holes for persons or animals to crawl through. In other cases, earth washes down against the fence, piles up against it, and finally damages the fencing from the pressure. The earth pile also makes it easier for intruders to climb over the fence.

3.5.4 Tanks

Care should be taken to ensure that the liquid being stored is compatible with the type of material from which the tank walls or lining are constructed. Changes in the use of a particular storage tank should be reviewed by the engineering organization prior to changing the contents of the tank.

Aboveground and elevated storage tanks usually fail from excessive corrosion to the tank walls. In some nonmetallic tanks, like those made from polymer resins, failure can occur due to cracking or chemical deterioration of the tank walls or linings.

Underground fuel storage tanks usually fail from rust perforation due to several effects of water inside the tank including—in the case of heating oil—a combination of water with sulfur in the fuel, bacterial action, and other factors. External rust, unless very heavy, is not highly correlated with internal rust. Leaks can occur due to tank damage or at piping connections.

3.6 Troubleshooting Failures

In order to arrive at an economically feasible decision, the cause of the deterioration must first be determined. This is often difficult to accomplish. Frequently, in fact, the exact cause may never be found, and the best anyone can do is to narrow the problem down to two or more causes and then repair for all of them. The actual method used in the determination process can be either the direct method or a process of elimination.

The first method is the one in which the cause is known directly from the type and extent of deterioration. This method requires little or no guesswork as to what the cause is. An example of this would be a localized failure of a steel building column caused by impact from a piece of equipment.

The second method is, as stated, a process of elimination. Much time, money, and personnel can be expended in locating the cause by this method. However, in many cases, it is the only way. Additional guidance on system and equipment troubleshooting techniques is provided in EPRI report 1003093, *System and Equipment Troubleshooting Guideline* [6].

The charts and tables in this section can be used as tools in the process of elimination. Their use will aid one to arrive more quickly at the cause or causes of deterioration. Some tips that the reader may find helpful in locating the cause of causes are listed below.

3.7 Estimating Design Life

Nearly all building elements and system components have a life expectancy that is commonly promoted by each respective manufacturer. However, in most cases, many assumptions have been made in order to satisfy the life expectancies stated, and in reality, the item will probably not last as long as anticipated. It is often useful to know the expected lifetime of the component under consideration when deciding whether to replace or repair it.

The preventive, predictive, and RCM practices recommended in this guide should assist each user in developing a program that maximizes the service life of building elements and system components. Appendix B of this report provides tables that provide estimated/suggested design lives for various building components.

4
CONDITION-BASED MONITORING

4.1 Introduction

4.1.1 General Facilities Inspection Guidance

After the behavior and properties of materials are understood, the facilities maintenance manager should learn to detect and control these properties. This can be successfully accomplished by implementing a formal inspection program. Allocating time and money to inspection is important for the following reasons:

- To locate any new deterioration that has taken place since the last inspection
- To review the existing conditions of the materials in the building, including equipment
- To follow up on repairs that have been accomplished since the last inspection
- To evaluate present housekeeping procedures

The inspection process should be structured as a set of formal guidelines or procedures. These general guidelines should establish the following criteria:

- The frequency of inspection, which depends on the available personnel and items being inspected
- Where to begin the inspection process
- The order of inspection (a set of inspection priorities)
- Information about how to inspect any one specific component, material, or facility
- The types of things to look for relative to the degree of deterioration
- Determination of probable causes of deterioration
- How to record and document what is observed

4.1.2 Recommended Inspection Frequencies

Recommended inspection frequencies are provided in Table 4-1 and detailed inspection criteria are provided in Section 4.2.

Table 4-1
Recommended Inspection Frequencies [1]

Item/Facility Element	Inspection Frequency
Major Structural Materials	
Reinforced concrete	
• Walls	Annually
• Retaining walls	Annually
• Tunnels and underground structures	Annually
• Seawalls and breakwaters	Annually
Structural steel	
• Roof trusses	Annually
• Steel poles and structures	Annually
Wood/timber	
• Wood poles and accessories	Annually
• Roof trusses	Annually
Facility Finish Materials	
Exterior materials	
• Chimneys and stacks	Annually
Interior ceiling and wall materials	Annually
Floors	Weekly
Roofs	Semiannually
Windows and doors	Semiannually
Coating systems	Annually
Facility Systems	
Plumbing systems	
• Water heaters	Quarterly
• Sump pumps and bilge	Quarterly
• Sewage pumps	Quarterly
• Sludge pumps	Quarterly
• Steam traps	Quarterly
HVAC systems	
• Roof ventilators: motor operated	Quarterly
• Roof ventilators: natural draft or wind operated	Annually
• Ventilating systems	Quarterly
• Exhaust air systems: showers and toilets	Semiannually
• Heating equipment	Semiannually
• Air conditioning equipment	Quarterly
Lighting: exterior/interior	Semiannually
Fire protection	Semiannually
Alarm and public address	Monthly
Conveying systems	Quarterly

Table 4-1 (cont.)
Recommended Inspection Frequencies [1]

Item/Facility Element	Inspection Frequency
External Systems	
Walks, drives, curbs, and asphalt surfaces	Semiannually
Runoff, drainage, and erosion control systems	Annually
Fences • Perimeter barriers • Other	 Monthly Annually
Tanks	Semiannually

4.2 Inspection of Major Structural Materials

4.2.1 Reinforced Concrete

4.2.1.1 General Inspection Criteria



Key Technical Point

The most important tool in determining types of deterioration in concrete is visual inspection.

The American Concrete Institute (ACI) has developed a "Survey of Existing Concrete," which can be an effective tool in the inspection process, and is presented, in part, in Table 4-2.

Table 4-2
Survey of Existing Concrete
(Courtesy of the American Concrete Institute)

Inspection/Survey Criteria	Observed Condition and Results
1. Description of Structure or Pavement	
Name, location, type, and size	
Owner, contractor, when built	
Design Architect and/or engineer Intended use and history of use Special features	
Photographs General view Detailed close ups of condition of area	
Sketch map: orientation showing sunny and shady walls and well and poorly drained regions	
2. Present Condition of Structure	
Overall alignment of structure Settlement	

Table 4-2 (cont.)
Survey of Existing Concrete
(Courtesy of The American Concrete Institute)

Inspection/Survey Criteria	Observed Condition and Results
Deflection Expansion Contraction	
Portions showing distress (such as beams, columns, pavement, and walls, subjected to strains and pressures)	
Surface condition of concrete General Cracks Location and frequency Type and size Leaching, stalactites Scaling Area, depth Type Spalls and popouts Number, size, and depth Type Extent of corrosion or chemical attack Stains Exposed steel Previous patching or other repair Interior condition of concrete Strength of cores Density of cores Moisture content (degree of saturation) Evidence of alkali-aggregate or other reaction Bond to aggregate, reinforcing steel, joints Pulse velocity Volume change Air content and distribution	
3. Nature of Loading and Detrimental Elements	
Nature or types of exposure Environment: arid, subtropical, marine, and so on Freezing and thawing Wetting and drying Drying under dry atmosphere Chemical attack: sulfates, acids Abrasion, erosion, cavitation Electric currents Drainage Loading Soils	

Table 4-2 (cont.)
Survey of Existing Concrete
(Courtesy of The American Concrete Institute)

Inspection/Survey Criteria	Observed Condition and Results
4. Original Condition of Structure	
5. Materials of Construction	
Hydraulic cement Coarse aggregate Fine aggregate Mixing water Air-entraining agents Admixtures Concrete	
6. Construction Practices	
7. Initial Physical Properties of Hardened Concrete	
Strength: compressive, flexural, elastic modulus Density Percentage and distribution of air Volume change potential Thermal properties	
8. Additional Items Pertaining to Pavements	
Structural section Joints Cracks	

4.2.1.2 Inspection Criteria for Slabs on Grade

Inspection of slabs on grade should include the following:

- Check for overall water tightness, including the presence of, and location and duration of, any water leaks. Verify any historical information concerning leaks. Leaks can signify cracks or excessive hydrostatic pressure.
- Check the general appearance of foundation wall or substructure for any stress-related conditions. Determine the type of stress as tension, compression, shear, bending, or buckling.
- Check for uneven settlement by observing the condition of existing grade on exterior, foundation, or slab surface.
- Check for uplift or the presence of hydrostatic pressure causing upward movement of existing grade, foundation wall, or slab.

- Check the slab for any structural modifications, new equipment on old slabs, old equipment since removed, subslab pits (new or filled in), and traffic usage changes.
- Check for exposure conditions, specifically chemical attack and freeze/thaw action.
- Check all previous repairs for conditions of any possible cracking or deterioration.

4.2.1.3 Inspection Criteria for Cast-in-Place Concrete Beams and Columns

Inspection of cast-in-place concrete beams and columns should include the following:

- Check general appearance for any stress-related conditions. Determine the type of stress as one or more of the following:
  - Tension (pulling force): causes crushing and usually no spalling.
  - Compression (pushing or crushing force): causes crushing or spalling.
  - Shear (slicing action): causes diagonal or stepped cracking from point of maximum load or shear.
  - Bending (combination of tension and compression): causes cracking with no spalling.
  - Buckling is a form of bending, and the condition is most visible at the outermost fibers on one side of the member. Buckling is usually associated with a high probability of failure.
- Check for uneven settlement by observing the condition of the existing grade on the exterior or the condition of the foundation slab.
- For columns, check for uplift or the presence of hydrostatic pressure causing upward movement of existing grade or slab.
- Check for exposure conditions, specifically chemical attack (that is, is surface material resistant to process contamination?), impact exposure, efflorescence, staining and rust, dusting, surface deterioration, decay, splitting, and operation or misuse of material, and the extent of each.
- Check all previous repairs for any possible cracking or deterioration.
- Check for any exposed reinforcement and extent of rust or deterioration.
- Check all sealant, expansion/contraction joints, and mortar and grout joints for deterioration or cracking.

4.2.1.4 Inspection Criteria for Loaded Precast Concrete Beams and Columns

Inspection of loaded precast concrete beams and columns should include the following:

- Check general appearance for any stress-related conditions. Determine the type of stress as one or more of the following:
  - Tension (pulling force): causes crushing and usually no spalling.
  - Compression (pushing or crushing force): causes crushing or spalling.

  - Shear (slicing action): causes diagonal or stepped cracking from point of maximum load or shear.
  - Bending (combination of tension and compression): causes cracking with no spalling.
  - Buckling is a form of bending, and the condition is most visible at the outermost fibers on one side of the member. Buckling is usually associated with a high probability of failure.
- Check for uneven settlement by observing condition of existing grade on exterior or condition of foundation slab.
- Check for improper design and construction conditions that can cause deficiencies such as cracking and surface deterioration.
- For columns, check for uplift or presence of hydrostatic pressure causing upward movement of existing grade or slab.
- Check for exposure conditions, specifically chemical attack (that is, is surface material resistant to process contamination?), impact exposure, efflorescence, staining and rust, dusting, surface deterioration, decay, splitting, and operation or misuse of material, and the extent of each.
- Check all previous repairs for any possible cracking or deterioration.
- Check for any exposed reinforcement and extent of rust or deterioration.
- Check for improperly designed or placed anchorage components. Verify that anchorage is intact and properly tightened.
- Check all sealant, expansion/contraction joints, and mortar and grout joints for deterioration or cracking.

4.2.2 Structural Steel

4.2.2.1 General Inspection Criteria

Structural steel has its own peculiar needs in terms of maintenance and repair. An effective plant maintenance program should include a formal inspection on a regular basis.



Key Technical Point

As with any structural-type members, not only should the members be inspected, but also their connections to other members.

When performing the inspection, notes should be made as to the present condition of the structural steel, the observable surface deterioration (such as defects and rusting), and the dates the particular element was repaired. Table 4-3 provides a list of inspection criteria for both structural members and connections.

Table 4-3
Inspection Criteria for Structural Steel [1]

Type of Structural Steel	Inspection Criteria
Structural members: • Roof trusses • Open web joists • Platform supports • Equipment supports • Stairs • Bearing and base plates • Siding girts • Roof purlins • Bridging • Steel decking • Bracing (vertical and horizontal) • Knee braces • Columns • Crane rails • Beams and girders • Plate and shells • Stacks	Inspect for the following: • Cracks • Localized distortion • Failure of paint or other protective coating • Unusual wear such as impact failure • Misalignment • Plumb (of vertical members) • Corrosion • Stress marks (appearing on coating) • General cleanliness
Connections: • Bolts • Welds • Anchor bolts • Rivets • Splices (beams and columns) • Connecting plates and angles	Check for the following: • Corrosion: general • Loosening of bolts and/or rivets • Cracks in welds • Local distortion • Corrosion: specific (rust ring worn through paint by connection head) • Unusual wear (destruction of bolt threads) • Protective coating failure • General cleanliness

4.2.2.2 Inspection Criteria for Steel Beams and Columns

Inspection of steel beams and columns should include the following:

- Check general appearance for any stress-related conditions. Identify the type of stress as one or more of the following:
  - Tension (pulling force): causes crushing and usually no spalling.
  - Compression (pushing or crushing force): causes crushing or spalling.
  - Shear (slicing action): causes diagonal or stepped cracking from point of maximum load or shear.

  - Bending (combination of tension and compression): causes cracking with no spalling.
  - Buckling is a form of bending, and the condition is most visible at the outermost fibers on one side of the member. Buckling is usually associated with a high probability of failure.
- Check for uneven settlement by observing condition of existing grade on exterior or condition of foundation slab.
- For columns, check for uplift or presence of hydrostatic pressure causing upward movement of existing grade or slab.
- Check for exposure conditions, specifically chemical attack (that is, is surface material resistant to process contamination?), impact exposure, efflorescence, staining and rust, surface deterioration, decay, splitting, and operation or misuse of material, and the extent of each.
- Check all previous repairs for any possible cracking or deterioration.
- Check for improper or damaged welds and Lamellar tearing of weld joints.
- Check condition of anchorage to verify that it is intact and properly tightened.
- Check bearing plates for proper bearing, anchorage, and deterioration.

4.2.2.3 Inspection Criteria for Pre-Engineered Metal Building Systems

Inspection of pre-engineered metal building systems should include the following:

- Check general appearance for any stress-related conditions. Determine the type of stress as one or more of the following:
  - Tension (pulling force): causes crushing and usually no spalling.
  - Compression (pushing or crushing force): causes crushing or spalling.
  - Shear (slicing action): causes diagonal or stepped cracking from point of maximum load or shear.
  - Bending (combination of tension and compression): causes twisting of the member.
- Check for uneven settlement by observing condition of existing grade on exterior or condition of foundation slab.
- Check for improper design and construction conditions that can cause deficiencies.
- Check bearing plates and anchor bolts for proper anchorage, bearing, and deterioration.
- Check structural members for level or plumb and true.
- For columns, check for uplift or presence of hydrostatic pressure causing upward movement of existing grade or slab.
- Check for exposure conditions, specifically chemical attack (that is, is surface material resistant to process contamination?), impact exposure, efflorescence, staining and rust, surface deterioration, decay, splitting, and operation or misuse of material, and the extent of each.
- Check all previous repairs for any possible cracking or deterioration.

- Check for improper or damaged welds and Lamellar tearing of weld joints.
- Check condition of fasteners and bolts to verify that they are intact and properly tightened.
- Check all bracing and tie rods for any damage and tightness.
- Check for water tightness or extent of leaks.
- Check moisture strips and joint sealants for damage and/or deterioration.
- Check bearing plates for proper bearing, anchorage, and deterioration.

4.2.3 Wood/Timber

4.2.3.1 General Inspection Criteria

Table 4-4 provides a list of inspection criteria for various wood/timber building elements.

Table 4-4
Inspection Criteria for Wood/Timber Building Elements [1]

Type of Wood/Timber Item	Inspection Criteria
• Sills and plates • Beams and girders (ledgers) • Rafters • Joists • Columns (posts) • Bridging • Headers • Studs • Lintels • Stairs • Wood trusses • Nailers • Finish wall and ceiling covering • Finish floor covering • Subfloors • Fascia and related trim • Finish trim • Other millwork • Laminated wood members	Inspect for the following: • Decay • Marine borers • Insect damage • Rodent damage • Fire damage • Splitting • Checking • Misalignment • Soundness of wood • Loosened laminate • Loosened connections • Holes in wood (possibly with small piles of sawdust)

4.2.3.2 Decay

Untreated lumber is subject to wood decay. Wood decay is caused by wood-rotting fungi that grow in damp wood. Fungi attack wood members in contact with damp masonry foundations, moist ground, or standing water, and water pipes that accumulate condensation or on which moisture condenses. Poor ventilation around the wood hastens the process of decay. Common signs of wood decay are the following:

- A damp appearance and a musty odor
- Opening or crumbling of the wood
- The presence of fine, dusty, reddish-brown powder under the building or structure
- A hollow sound when timber is tapped
- Easy penetration of timber by a sharp-pointed tool

4.2.3.3 Marine Borers

Marine borers are found in brackish waters and are especially active when the water temperature is in the 50ºF range. The damage by marine borers can be controlled by natural conditions of salinity, temperature, turbidity, current, or pollution. Means of improving the resistance of existing structures to marine borers' attack are often expensive. The only effective method is armoring, which is considered to be more of a repair than a preventive maintenance activity.

4.2.3.4 Insects

Insects that can cause wood damage are listed in Table 4-5.

Table 4-5
Insects That Cause Wood Damage [1]

Insect Type	Type of Damage
Beetles	Burrow through and excavate channels on surface layers
Carpenter ants and bees	Burrow in the wood and make homes, but do not feed on the wood
Termites	Bore and eat into wood or other cellulose material such as fiberboard

Termites are the most destructive of the insects listed in Table 4-5. They are found in most regions of the United States, but are most active along the Pacific and Gulf Coasts and in some of the South Atlantic and Southwest states.

Subterranean termites. These termites account for 95% of all termite damage in the United States. They live in nests and develop their colonies underground, but they build tunnels through the earth to get at wood or other cellulose material such as fiberboard, fabric, and paper. Therefore, the evidence that this species is active is in the form of soil mounds or tubes in areas such as along or inside of foundations or under porches.

Swarming termites. The other type of termites enter the facility or building directly at the time of swarming activity. They frequently attack wood that has a high moisture content and can be found in decaying wood. Swarming termites set up colonies and live in the wood. There is little—if any—evidence of their existence. They can cause destruction from within the timber.

4.2.3.5 Inspection Criteria for Wood Beams and Columns

Inspection of wood beams and columns should include the following:

- Check general appearance for any stress-related conditions. Determine the type of stress as one or more of the following:
  - Tension (pulling force): causes crushing and usually no spalling.
  - Compression (pushing or crushing force): causes crushing or spalling.
  - Shear (slicing action): causes diagonal or stepped cracking from point of maximum load or shear.
  - Bending (combination of tension and compression): causes cracking with no spalling.
  - Buckling is a form of bending, and the condition is most visible at the outermost fibers on one side of the member. Buckling is usually associated with a high probability of failure.
- Check for uneven settlement by observing condition of existing grade on exterior or condition of foundation slab.
- Check for improper design and construction conditions that can cause deficiencies such as cracking and surface deterioration.
- For columns, check for uplift or presence of hydrostatic pressure causing upward movement of existing grade or slab.
- Check for exposure conditions, specifically chemical attack (that is, is surface material resistant to process contamination?), impact exposure, staining, dry rot, surface deterioration, decay, splitting, and operation or misuse of material, and the extent of each.
- Check all previous repairs for any possible cracking or deterioration.
- Check for improperly designed or placed anchorage components. Verify that anchorage is intact and properly tightened.
- Check for any splitting, cracking, or deterioration of surface.
- Check all sealant, expansion/contraction joints, and mortar and grout joints for deterioration or cracking.

4.2.3.6 Inspection Criteria for Pre-Engineered Wood Building Systems

Inspection of pre-engineered wood building systems should include the following:

- Check general appearance for any stress-related conditions. Determine the type of stress as one or more of the following:
  - Tension (pulling force): causes crushing and usually no spalling.
  - Compression (pushing or crushing force): causes crushing or spalling.
  - Shear (slicing action): causes diagonal or stepped cracking from point of maximum load or shear.
  - Bending (combination of tension and compression): causes cracking with no spalling.
  - Buckling is a form of bending, and the condition is most visible at the outermost fibers on one side of the member. Buckling is usually associated with a high probability of failure.
- Check for uneven settlement by observing condition of existing grade on exterior or condition of foundation slab.
- Check bearing plates and anchor bolts for proper anchorage, bearing, and deterioration.
- Check structural members for level or plumb and true.
- Check for water damage or spongy/soft areas.
- Check for fire- or heat-damaged surfaces resulting in deteriorated areas.
- Check for improper design and construction conditions that can cause deficiencies such as cracking and surface deterioration.
- For columns, check for uplift or presence of hydrostatic pressure causing upward movement of existing grade or slab.
- Check for exposure conditions, specifically chemical attack (that is, is surface material resistant to process contamination?), impact exposure, staining, dry rot, surface deterioration, decay, splitting, and operation or misuse of material, and the extent of each.
- Check all previous repairs for any possible cracking or deterioration.
- Check for improperly designed or placed anchorage components. Verify that anchorage is intact and properly tightened.
- Check for any splitting, cracking, or deterioration of surface.
- Check all sealant, expansion/contraction joints, and mortar and grout joints for deterioration or cracking.

4.2.3.7 Inspection Criteria for Column Fireproofing

Inspection of column fireproofing should include the following:

- Check general appearance for any stress-related conditions. Determine the type of stress as one or more of the following:
  - Tension (pulling force): causes crushing and usually no spalling.
  - Compression (pushing or crushing force): causes crushing or spalling.

  - Shear (slicing action): causes diagonal or stepped cracking from point of maximum load or shear.
  - Bending (combination of tension and compression): causes cracking with no spalling.
  - Buckling is a form of bending, and the condition is most visible at the outermost fibers on one side of the member. Buckling is usually associated with a high probability of failure.
- Check for uneven settlement by observing condition of existing grade on exterior or condition of foundation slab.
- Check for uplift or presence of hydrostatic pressure causing upward movement of existing grade or slab.
- Check for exposure conditions, specifically chemical attack (that is, is surface material resistant to process contamination?), impact exposure, efflorescence, staining and rust, dusting, surface deterioration, decay, splitting, and operation or misuse of material, and the extent of each.
- Check for water or moisture damage causing material deterioration and breakdown.
- Check all previous repairs for any possible cracking or deterioration.

4.3 Inspection of Facility Finish Materials

4.3.1 Exterior Materials

4.3.1.1 Wood Exteriors

Wood exteriors can include sidings constructed of wood shingles, weatherboard siding, or plywood. Wood exteriors should be regularly inspected for damage from wear, accidents, and the elements. Painting and surface treatments should be inspected quarterly for deterioration; exteriors should be checked for loose, warped, cracked, or broken boards and shingles.

Make a careful check to determine that existing structural, functional, and material conditions warrant repair to the existing wall rather than complete re-siding, insulation, or other overall repair or rehabilitation.

4.3.1.2 Metal Exteriors

Metal exteriors can include sidings constructed of corrugated iron or steel, aluminum, enamel-coated steel, and protected metals. Metal exteriors should be regularly inspected for damage from abrasion, wear, corrosion, physical deformation, misalignment, and loosening.

Precision shop fabrication of metal siding and new methods of fastening panels with interlocking joints and clips generally ensure against misalignment when erecting metal buildings. Buildings can sag, lean, or suffer surface damage from foundation settlement, heavy wind pressures,

corrosion, and impact from heavy objects or vehicles. Constant vibration makes more frequent inspection of sheeting fasteners necessary.

4.3.1.3 Masonry and Concrete Exteriors

Exteriors should be inspected quarterly for structural cracks, open mortar joints, settlement, efflorescence, stains, parapet creep, and deterioration of paint or other surface covering.

Efflorescence. Efflorescence usually appears as a light powder or crystallization caused by water-soluble salts deposited as water evaporates within the mortar on the masonry unit. Aside from detracting from the appearance of a wall, efflorescence can indicate moisture penetration into the wall. An inspection should be made to determine the source of the stain. If efflorescence appears at the edges and not near the center of the masonry unit, the mortar is probably at fault; if it appears near the center of the unit only, the masonry unit is at fault.

Cracks. Types of cracks encountered in brick, concrete block, and stone exterior surfaces include the following:

- **Horizontal-movement cracks.** These cracks are usually long, wide cracks in the mortar joint that occur along the line of the floor or roof slab or along the line of lintels over the window. Where these cracks turn the corner of a building, they frequently crack down.
- **Vertical- and diagonal-movement cracks.** These cracks generally occur near the ends or offsets of buildings. They can also be found extending from a window sill to the lintel of a door or window on a lower floor. These can vary from 1/8 to 3/8 in. in width and follow the mortar joints, but in some instances they can break through the bricks or other masonry.
- **Shrinkage cracks.** These cracks are fine, hairline cracks that are found in mortar as well as in concrete walls. The most noticeable ones are those running vertically, but a close examination of a section of wall that leaks can also show them in the horizontal or bed joints of brick or block walls.

Parapet creep. Unequal expansion of roof slabs and brick parapets sometimes causes parapet corners to creep. When this happens, the horizontal mortar joint at the top of the slab or the nearest through-wall flashing usually shears open. The parapet then extends beyond the face of the wall below, at the corners. If the creep action continues to the extent that cracks extend through the parapet and concrete from the spandrel beam, and brick and mortar begin to break off, an engineering evaluation and major repairs are probably necessary.

4.3.1.4 Mineral-Surfaced Board Exteriors

These products should be inspected annually for evidence of physical distortion, swelling, cracking, or warping. Stains can provide an indication of water penetration, which can cause the failures noted.

4.3.2 Interior Ceiling and Wall Materials

4.3.2.1 General Inspection Criteria

Interior ceiling and wall materials should be visually inspected at least annually. Inspections should identify the following defects based on the type of material:

- Acoustical tile: staining, cracking, discoloration, permanent bending, swelling, and warping
- Brick or block: cracks, staining, loose mortar, and missing bricks/blocks
- Corrugated plastic sheeting: cracks, fading, and chipping around the edges
- Glass blocks: cracks and loose mortar
- Plaster: loose plaster, map cracks, shrinkage cracks, and structural cracks
- Plastic blocks: cracks, loose mortar, and discoloration
- Stone and artificial stone: cracks, staining, loose mortar, and missing bricks/blocks
- Wallboards and plasterboards: cracks, staining, swelling, warping, loose nails/screws, holes, dents, and cracks at joints
- Wood: excessive splitting and checking, decay (rot), and charring

4.3.2.2 Inspection Criteria for Conventional Partitions

Inspection of conventional partitions should include the following:

- Check general appearance for any stress-related conditions. Identify the type of stress as one or more of the following:
  - Tension (pulling force): causes crushing and usually no spalling.
  - Compression (pushing or crushing force): causes crushing or spalling.
  - Shear (slicing action): causes diagonal or stepped cracking from point of maximum load or shear.
  - Bending (combination of tension and compression): causes cracking with no spalling.
- Check for uplift or presence of hydrostatic pressure causing upward movement of existing grade, slab, or wall.
- Check for exposure conditions, specifically chemical attack (that is, is surface material resistant to process contamination?), impact exposure, staining and rust, dusting, surface deterioration, pitting, spalling, operation or misuse of material, and extent of each.
- Check all previous repairs and patches for possible cracking and deterioration.
- Check for any exposed reinforcement and extent of rust or deterioration in masonry or concrete partitions.
- Check all sealant, expansion/contraction joints for cracking or deformation, and mortar and grout joints for deterioration, cracking, or missing sections.

- Check for dampness and/or stains. Note location and determine type of stain and cause.
- Check for microorganism growth such as molds, fungi, mildew, or rot.
- Check surface finish for any damage or deterioration.
- Check for damage at surface bond to substrate or anchorage to supports. Check for sagging, loose spots, or pulling away. Check any fasteners for damaged, deteriorated, loose, or missing conditions.

4.3.2.3 Inspection Criteria for Specialty Partitions

Inspection of specialty partitions should include the following:

- Check for uplift or presence of hydrostatic pressure causing upward movement of existing grade, slab, or wall.
- Check for exposure conditions, specifically chemical attack (that is, is surface material resistant to process contamination?), impact exposure, staining and rust, surface deterioration, pitting, spalling, operation or misuse of material, and extent of each.
- Check all previous repairs and patches for possible cracking and deterioration.
- Check all sealant, expansion/contraction joints for cracking or deformation and deterioration.
- Check for stains. Note location and determine type of stain and cause.
- Check condition and operation of all tracks, hardware, and controls.
- Check condition of any anchorage for damage or deterioration.
- Check operation of movable partitions for any deficiencies, based on the manufacturer's design/functional requirements.

4.3.2.4 Inspection Criteria for Toilet Partitions

Inspection of toilet partitions should include the following:

- Check all toilet and shower partitions for cleanliness and to determine if resurfacing or painting is required.

4.3.2.5 Inspection Criteria for Wall Covering Systems

Inspection of wall covering systems should include the following:

- Check for exposure conditions, specifically chemical attack (that is, is surface material resistant to process contamination?), impact exposure, staining and rust, surface deterioration, pitting, spalling, operation or misuse of material, and extent of each.
- Check all previous repairs and patches for possible cracking and deterioration.
- Check for loose, damaged, or missing fasteners.

- Check for warped, split, curled, rotted, decayed, or deteriorated wood surfaces.
- Check for degradation, cracking, and brittleness.
- Check all seams for separation, deterioration, and looseness.
- Check condition of sealants including cracking, deformation, and deterioration.
- Check condition of any paint or coatings for damage or deterioration such as cracks, peeling, or flaking.
- Check for any plant or microorganism growth such as bacteria, molds, or fungi.
- Check for insect damage (that is, termites and carpenter ants).
- Check condition of anchorage to verify that it is intact and properly tightened.

4.3.2.6 Inspection Criteria for Ceiling Systems

Inspection of ceiling systems should include the following:

- For concrete ceilings, check for cracked, spalling, and exposed, corroded reinforcing. If water is present, determine the source.
- For drywall/plaster ceilings, inspect for cracked or missing sections, bowing, and/or evidence of water damage.
- For acoustical ceilings, check both tile and grid suspension system. Note any broken or missing tiles, loose support grids, and/or any evidence of water damage.
- Check metal ceiling systems for signs of corrosion (due to water leaks or area environmental conditions), bowed or dented sections, and any missing pieces.
- For wood ceilings, inspect for damage due to water leaks, bowed areas, or missing sections.

4.3.3 Floors and Stairs

It is not enough to inspect floors on a yearly or semiannual inspection tour of the facility. Floors should be continually inspected and minor defects corrected before they become major problems. Floors should be visually inspected for evidence of cracks, discoloration, stains, tears, fading, excessive abrasion, buckling, or corrosion.

The inspection criteria provided for each type of floor surface also applies to stairs made from the same material. Stair inspections should also, however, include an inspection of railings, kickplates, and banisters to verify their structural integrity and any evidence of deterioration, corrosion, cracking, or looseness.

4.3.3.1 Inspection Criteria for Cast-in-Place Concrete Floors

Inspection of cast-in-place concrete floors should include the following:

- Check general appearance for any stress-related conditions. Identify the type of stress as being one or more of the following:
  - Tension (pulling force): causes crushing and usually no spalling.
  - Compression (pushing or crushing force): causes crushing or spalling.
  - Shear (slicing action): causes diagonal or stepped cracking from point of maximum load or shear.
  - Bending (combination of tension and compression): causes cracking with no spalling.
- Check for uneven settlement by observing condition of existing grade on exterior or condition of foundation slab.
- Check for improper design and construction conditions such as cracking and surface deterioration that can cause deficiencies.
- Check for exposure conditions, specifically chemical attack (that is, is surface material resistant to process contamination?), impact exposure, efflorescence, staining and rust, dusting, surface deterioration, decay, splitting, and operation or misuse of material, and the extent of each.
- Check all previous repairs for any possible cracking or deterioration.
- Check for any exposed reinforcement and extent of rust or deterioration.
- Check all sealant, expansion/contraction joints, and mortar and grout joints for deterioration or cracking.

4.3.3.2 Inspection Criteria for Precast Concrete Floors

Inspection of precast concrete floors should include the following:

- Check general appearance for any stress-related conditions. Identify the type of stress as being one or more of the following:
  - Tension (pulling force): causes crushing and usually no spalling.
  - Compression (pushing or crushing force): causes crushing or spalling.
  - Shear (slicing action): causes diagonal or stepped cracking from point of maximum load or shear.
  - Bending (combination of tension and compression): causes cracking with no spalling.
- Check for uneven settlement by observing condition of existing grade on exterior or condition of foundation slab.
- Check for improper design and construction conditions such as cracking and surface deterioration that can cause deficiencies.
- Check for exposure conditions, specifically chemical attack (that is, is surface material resistant to process contamination?), impact exposure, efflorescence, staining and rust, dusting, surface deterioration, decay, splitting, and operation or misuse of material, and the extent of each.

- Check all previous repairs for any possible cracking or deterioration.
- Check for any exposed reinforcement and extent of rust or deterioration.
- Check for improperly designed or placed anchorage components. Verify that anchorage is intact and properly tightened.
- Check all sealant, expansion/contraction joints, and mortar and grout joints for deterioration or cracking.

4.3.3.3 Inspection Criteria for Steel Floors

Inspection of steel floors should include the following:

- Check general appearance for any stress-related conditions. Identify the type of stress as being one or more of the following:
  - Tension (pulling force): causes crushing and usually no spalling.
  - Compression (pushing or crushing force): causes crushing or spalling.
  - Shear (slicing action): causes diagonal or stepped cracking from point of maximum load or shear.
  - Bending (combination of tension and compression): causes twisting and tearing.
- Check for uneven settlement by observing condition of existing grade on exterior or condition of foundation slab.
- Check for improper design and construction conditions that can cause deficiencies.
- Check for exposure conditions, specifically chemical attack (that is, is surface material resistant to process contamination?), impact exposure, efflorescence, staining and rust, corrosion, surface deterioration, and operation or misuse of material, and the extent of each.
- Check all previous repairs for conditions of any possible failures or deterioration.
- Check for improper or damaged welds and Lamellar tearing of weld joints.
- Check condition of anchorage to verify that it is intact and properly tightened.

4.3.3.4 Inspection Criteria for Composite Floors

Inspection of composite floors should include the following:

- Check general appearance for any stress-related conditions. Identify the type of stress as being one or more of the following:
  - Tension (pulling force): causes crushing and usually no spalling.
  - Compression (pushing or crushing force): causes crushing or spalling.
  - Shear (slicing action): causes diagonal or stepped cracking from point of maximum load or shear.
  - Bending (combination of tension and compression): causes cracking with no spalling or twisting and tearing.

- Check for uneven settlement by observing condition of existing grade on exterior or condition of foundation slab.
- Check for improper design and construction conditions that can cause deficiencies.
- Check for exposure conditions, specifically chemical attack (that is, is surface material resistant to process contamination?), impact exposure, efflorescence, staining and rust, dusting, surface deterioration, decay, splitting, and operation or misuse of material, and the extent of each.
- Check all previous repairs for any possible cracking, deterioration, or failures.
- Check for any exposed reinforcement and extent of rust or deterioration.
- Check all sealant, expansion/contraction joints, and mortar and grout joints for deterioration or cracking.
- Check for improper or damaged welds and Lamellar tearing of weld joints.
- Check condition of anchorage to verify that it is intact and properly tightened.

4.3.3.5 Inspection Criteria for Wood Floors

Inspection of wood floors should include the following:

- Check general appearance for any stress-related conditions. Identify the type of stress as being one or more of the following:
  - Tension (pulling force): causes crushing and usually no spalling.
  - Compression (pushing or crushing force): causes crushing or spalling.
  - Shear (slicing action): causes diagonal or stepped cracking from point of maximum load or shear.
  - Bending (combination of tension and compression): causes cracking.
- Check for uneven settlement by observing condition of existing grade on exterior or condition of foundation slab.
- Check for improper design and construction conditions such as cracking and surface deterioration that can cause deficiencies.
- Check for exposure conditions, specifically chemical attack (that is, is surface material resistant to process contamination?), freeze/thaw action, impact exposure, staining, dry rot, surface deterioration, decay, splitting, and operation or misuse of material, and the extent of each.
- Check all previous repairs for any possible deterioration.
- Check for improperly designed or placed anchorage components. Verify that anchorage is intact and properly tightened.
- Check for any splitting, cracking, or deterioration of surface.

- Check all sealant, expansion/contraction joints, and mortar and grout joints for deterioration or cracking.
- Check for water damage or spongy/soft areas.
- Check for fire- or heat-damaged surfaces resulting in deteriorated areas.

4.3.3.6 Inspection Criteria for Floor-Finishing Systems

Inspection of floor-finishing systems should include the following:

- Check for uneven settlement by observing condition of existing slab or subfloor.
- Check for any structural defect that can cause upward movement of the existing slab or subflooring, which can cause various floor finish defects.
- Check for exposure conditions, specifically chemical attack (that is, is surface material resistant to process contamination?), impact exposure, staining, dusting, surface deterioration, decay, splitting, and operation or misuse of material, and the extent of each.
- Check for water or moisture damage causing material deterioration and breakdown.
- Check all previous repairs and patches for any possible cracking and deterioration.
- Check for any plant or microorganism growth such as moss, bacteria, molds, and fungi.
- Check for any insect damage (that is, termites and carpenter ants).
- Check for damage at surface bond to substrate. Check for sagging, loose spots, or pulling away.
- Check for edge curling, tears, uneven appearance, and water spotting.
- Check for tile brittleness, grout deterioration, and broken tiles.
- Check for unevenness at joints, warped or buckled floors, and squeaks.
- Check carpet for worn spots, holes, tears, frayed edges, rough seams, and damaged seams.

4.3.4 Roofs

4.3.4.1 General Inspection Criteria

Roofing inspections should be done on a regular basis to ensure that the degradation of the roofing materials does not cause leakage or damage to the roof structure.



Key Technical Point

Inspection criteria that are common to all types of roofs are checking the general appearance of the roof surface, looking for any evidence of mechanical damage to the roofing system, and checking the water tightness of the roofing system.

4.3.4.2 Inspection Criteria for Concrete Roof Structures

Inspection of concrete roof structures should include the following:

- Check general appearance for any stress-related conditions. Identify the type of stress as being one or more of the following:
  - Tension (pulling force): causes crushing and usually no spalling.
  - Compression (pushing or crushing force): causes crushing or spalling.
  - Shear (slicing action): causes diagonal or stepped cracking from point of maximum load or shear.
  - Bending (combination of tension and compression): causes cracking with no spalling.
- Check for uneven settlement by observing condition of existing grade on exterior or condition of foundation slab.
- Check for improper design and construction conditions that can cause deficiencies such as cracking and surface deterioration.
- Check for exposure conditions, specifically chemical attack (that is, is surface material resistant to process contamination?), freeze/thaw action, impact exposure, efflorescence, staining and rust, dusting, surface deterioration, pitting, spalling, and operation or misuse of material, and the extent of each.
- Check all previous repairs for any possible cracking or deterioration.
- Check for any exposed reinforcement and extent of rust or deterioration.
- Check all sealant, expansion and contraction joints, and mortar and grout joints for deterioration or cracking. Inspect expansion and contraction joints for signs of damage. Ensure that the joints are clear of debris, such as built-up roof gravel. Ensure that the joint gap is within the appropriate design parameters. Inspect the joints from both the interior and exterior perspective to identify signs of past water leakage.
- Inspect the roof area surrounding roof drains for signs of cracking and loss of water tightness. Inspect the roof drains from both the interior and exterior perspective to identify signs of past water leakage.

4.3.4.3 Inspection Criteria for Steel Roof Structures

Inspection of steel roof structures should include the following:

- Check general appearance for any stress-related conditions. Identify the type of stress as being one or more of the following:
  - Tension (pulling force): causes crushing and usually no spalling.
  - Compression (pushing or crushing force): causes crushing or spalling.
  - Shear (slicing action): causes diagonal or stepped cracking from point of maximum load or shear.
  - Bending (combination of tension and compression): causes twisting and tearing.

- Check for uneven settlement by observing condition of existing grade on exterior or condition of foundation slab.
- Check for improper design and construction conditions that can cause deficiencies.
- Check for exposure conditions, specifically chemical attack (that is, is surface material resistant to process contamination?), freeze/thaw action, impact exposure, efflorescence, staining and rust, corrosion, surface deterioration, and operation or misuse of material, and the extent of each.
- Check all previous repairs and patches for any possible failures or deterioration.
- Check for improper or damaged welds and Lamellar tearing of weld joints.
- Check condition of anchorage to verify that it is intact and properly tightened.

4.3.4.4 Inspection Criteria for Wood Roof Structures

Inspection of wood roof structures should include the following:

- Check general appearance for any stress-related conditions. Identify the type of stress as being one or more of the following:
  - Tension (pulling force): causes crushing and usually no spalling.
  - Compression (pushing or crushing force): causes crushing or spalling.
  - Shear (slicing action): causes diagonal or stepped cracking from point of maximum load or shear.
  - Bending (combination of tension and compression): causes cracking and splitting. Bending is usually associated with a high probability of failure.
- Check for uneven settlement by observing condition of existing grade on exterior or condition of foundation slab.
- Check for improper design and construction conditions that can cause deficiencies such as cracking and surface deterioration.
- For columns, check for uplift or presence of hydrostatic pressure causing upward movement of existing grade or slab.
- Check for exposure conditions, specifically chemical attack (that is, is surface material resistant to process contamination?), freeze/thaw action, impact exposure, staining, dry rot, surface deterioration, decay, splitting, and operation or misuse of material, and the extent of each.
- Check all previous repairs for any possible cracking or deterioration.
- Check for improperly designed or placed anchorage components. Verify that anchorage is intact and properly tightened.
- Check all sealant, expansion and contraction joints, and mortar and grout joints for deterioration or cracking.
- Check for water damage or spongy/soft areas.
- Check for fire- or heat-damaged surfaces resulting in deteriorated areas.

4.3.4.5 Inspection Criteria for Built-Up Membrane Roofs

Inspection of built-up membrane roofs should include the following:

- Check general appearance and condition: check for debris, rags, leaves, and equipment that could cause blockage of roof drainage system.
- Check for overall water tightness, including presence of, or location and duration of, any water leaks. Verify any historical information such as leaks during long-continuing rain or leaks occurring every rain.
- Check roof membrane surface for splits, wrinkles, bubbles, buckling, alligator surfaces, and sponginess, and all seams for separating, splitting, deterioration, and looseness.
- Check for evidence of water accumulation. Accumulation causing ponds on the roof is best checked one to three days after precipitation to determine if water accumulation (lack of drainage) is indeed a problem.
- Check all flashing for wind damage, loss of bituminous coating, damaged caulking, curling, and exposed edges. Check flashing fasteners for looseness and deterioration. Check all metal gravel stops for damage and deterioration.
- Note that not all water entries into a building are caused by a leaking roof. Water problems can be caused by condensation, negative air pressure within the building, or entry through walls or mechanical equipment.
- If roof leaks are extensive, perform a flood test. Seal all storm water systems (that is, downspouts, roof drains, and scuppers). Flood to determine actual extent of leak problems.
- Check all pitch pockets for cracking, proper filling, and flashing and metal damage.
- Check seals on all roof penetrations for any deterioration.

4.3.4.6 Inspection Criteria for Single-Ply Membrane Roofs

Inspection of single-ply membrane roofs should include the following:

- Check general appearance and condition: check for debris, rags, leaves, and equipment that could cause blockage of roof drainage system.
- Check for overall water tightness, including presence of, or location and duration of, any water leaks. Verify any historical information such as leaks during long-continuing rain or leaks occurring every rain.
- Check for splits, wrinkles, bubbles, buckling sponginess, and loss of ballast, if applicable.
- Check all seams for separation, splitting, deterioration, and looseness.
- Check for evidence of water accumulation. Accumulation causing ponds on the roof is best checked one to three days after precipitation to determine if water accumulation (lack of drainage) is indeed a problem.
- Check all flashing for wind damage, loss of bituminous coating, damaged caulking, curling, and exposed edges. Check flashing fasteners for looseness and deterioration.

- Check all metal gravel stops for damage and deterioration.
- Check for excessive condensation.
- Check for algae, moss, and plant growth.
- Check for proper placement of ballast or roof anchorage.
- Check all roof penetrations for loose anchorage, cracks and holes.
- If roof leaks are extensive, perform a flood test. Seal all storm water systems (that is, downspouts, roof drains, and scuppers). Flood to determine actual extent of leak problems.

4.3.4.7 Inspection Criteria for Metal Roofing Systems

Inspection of metal roofing systems should include the following:

- Check general appearance and condition: check for debris, rags, leaves, and equipment that could cause blockage of roof drainage system.
- Check for overall water tightness, including presence of, or location and duration of, any water leaks. Verify any historical information such as leaks during long-continuing rain or leaks occurring every rain.
- Check for locations or presence of dampness and stains; note locations, types, and cause of stain.
- Check all seams and flashing for wind damage, damaged or missing fasteners, or other deterioration.
- Check all roof penetrations for loose anchorage, cracks, and holes.
- Check for excessive corrosion, pitting, scaling, finish loss, and damaged units.
- Check for loose or missing anchorage or movement, sagging, bending, or cracks.
- Check for excessive condensation.

4.3.4.8 Inspection Criteria for Coated Foam-Membrane Roofs

Inspection of coated foam membrane roofs should include the following:

- Check general appearance and condition: check for debris, rags, leaves, and equipment that could cause blockage of roof drainage system.
- Check for overall water tightness, including presence of, or location and duration of, any water leaks. Verify any historical information such as leaks during long-continuing rain or leaks occurring every rain.
- Check for splits, wrinkles, bubbles, buckling, holes, and sponginess.
- Check for surface deterioration, separation, splitting, and punctures in protective coating.
- Check for evidence of water accumulation. Accumulation causing ponds on the roof is best checked one to three days after precipitation to determine if water accumulation (lack of drainage) is indeed a problem.

- Check all flashing for wind damage, loss of coating, damaged caulking, curling, and exposed edges. Check flashing fasteners for looseness and deterioration.
- Check all metal gravel stops for damage and deterioration.
- Check seals on all roof penetrations and for any deterioration, cracks, or holes.
- Check for excessive condensation.
- Check for algae, moss, and plant growth.
- If roof leaks are extensive, perform a flood test. Seal all storm water systems (that is, downspouts, roof drains, and scuppers). Flood to determine actual extent of leak problems.

4.3.4.9 Inspection Criteria for Shingle Roofs

Inspection of shingle roofs should include the following:

- Check general appearance and condition: check for debris, rags, leaves, and equipment that could cause blockage of roof drainage system.
- Check for overall water tightness, including presence of, or location and duration of, any water leaks. Verify any historical information such as leaks during long-continuing rain or leaks occurring every rain.
- Check for worn, deteriorated, rotting, split, and missing shingles.
- Check for failed, loose, or missing fasteners.
- Check all flashing for soundness, wind damage, loose seams and edges, damaged caulking, curling, and exposed edges.
- Check roof penetrations, valleys, and ridges for any damage, deterioration, cracks, or holes.
- Check condition of any paints or coatings for cracks, peeling, stains, and deterioration.
- Check for excessive condensation.

4.3.4.10 Inspection Criteria for Tile Roofs

Inspection of tile roofs should include the following:

- Check general appearance and condition: check for debris, rags, leaves, and equipment that could cause blockage of roof drainage system.
- Check for overall water tightness, including presence of, or location and duration of, any water leaks. Verify any historical information such as leaks during long-continuing rain or leaks occurring every rain.
- Check for worn, deteriorated, cracked, loose, and missing tiles.
- Check for failed, loose, or missing fasteners.
- Check all flashing for soundness, wind damage, loose seams and edges, damaged caulking, curling, and exposed edges.

- Check roof penetrations for any damage, deterioration, cracks, or holes.
- Check condition of any paints or coatings for cracks, peeling, stains, and deterioration.
- Check for excessive condensation.

4.3.4.11 Inspection Criteria for Parapets

Inspection of parapets should include the following:

- Check general appearance and condition of construction material for cleanliness, damage, or deterioration.
- Check for structural-related stress in the form of cracks, popouts, or separations.
- Check condition of coping, counter flashing, base flashing, and expansion and contraction joints for wind damage, soundness, loose seams and edges, curling, exposed edges, holes, or openings.
- Check condition of sealants including cracking, deformation, or deterioration.
- Check for separation or gaps between the brick, stone, terra cotta, or concrete masonry units and the mortar and any deterioration or missing sections.
- Check the condition of the mortar joints relative to size, tooling, shrinkage, cracks, and voids.
- Check for locations or presence of dampness and/or stains. Note location and determine type of stain and cause.
- Check for step cracking, cracked units, fractured, pitted, spalling, or crumbling surfaces.
- Check for overall water tightness, including presence of, or location and duration of, any water leaks. Verify any historical information such as leaks during long-continuing rain or leaks occurring every rain.

4.3.4.12 Inspection Criteria for Roof Drainage Systems

Inspection of roof drainage systems should include the following:

- Check general appearance and condition of construction material for cleanliness, damage, or deterioration.
- Check all seams for separation, deterioration, and looseness.
- Check for obstructions to proper drain flow.
- Check for overall water tightness, including presence of, or location and duration of, any water leaks. Verify any historical information such as leaks during long-continuing rain or leaks occurring every rain.
- Check for missing or damaged anchors.
- Check condition of any paint or coatings for damage or deterioration such as cracks, peeling, or flaking.

- Check for any plant growth.
- Check for broken or clogged drains.
- Check for proper roof slope.
- Seal all storm water systems (that is, downspouts, roof drains, and scuppers). Flood test roof drainage system to determine water tightness and operation.

4.3.4.13 Inspection Criteria for Roof Specialties

For this report, roof specialties can include roof hatches, equipment curbs, ventilators, vents, coping, gravel stops, fascia, roof expansion joints, and associated work. Inspection of roof specialties should include the following:

- Check general appearance and condition of roof specialties for proper operation, surface deterioration, finish loss, damage, and missing parts.
- Check condition of flashing and curbs for wind damage, soundness, loose seams and edges, curling, exposed edges, and loose or missing fasteners.
- Check for overall water tightness, including presence of, or location and duration of, any water leaks. Verify any historical information such as leaks during long-continuing rain or leaks occurring every rain.
- Check for locations or presence of dampness and/or stains; note locations and determine type of stain and cause.
- Check all sealants for cracks, deformation, or deterioration.
- Check condition of gaskets and/or putty for deformation, and check for deterioration including any cracking or missing areas that could allow water penetration or glazing slippage.
- Check condition of metal frames and surfaces for indications of excessive corrosion, pitting, scaling, checking, warping, and finish loss.
- Check condition of wood frames for indications of wood rot, cracked and broken sections, and finish failure.
- Check operation and condition of hardware for smoke/explosion relief vents, roof hatches, ventilators, and vents where applicable. Identify any damaged, inoperative, or deteriorating conditions.
- If roof leaks are extensive, perform a flood test. Flood to determine actual extent of leak problems.

4.3.4.14 Inspection Criteria for Roof Skylights

Inspection of roof skylights should include the following:

- Check general appearance and condition of sealants for cracking, deformation, or deterioration.
- Check condition of flashing and curbs for wind damage, soundness, loose seams and edges, curling, exposed edges, and loose or missing fasteners.

- Check for overall water tightness, including presence of, or location and duration of, any water leaks. Verify any historical information such as leaks during long-continuing rain or leaks occurring every rain.
- Check for locations or presence of dampness and/or stains; note locations and determine type of stain and cause.
- Check condition of gaskets and/or putty for deformation, and deterioration including any cracking.
- Check general appearance and condition of metal frames for indications of excessive corrosion, pitting, scaling, checking, warping, and finish loss.
- Check condition of wood frames for indications of wood rot, cracked and broken sections, and finish failure.
- Check condition of glazing for cracked and broken sections, scratches, shrinkage, deflection, and deformation.
- If roof leaks are extensive, perform a flood test. Flood to determine actual extent of leak problems.

4.3.5 Windows and Doors

Windows and doors are key building elements that often get extensive use by the occupants of a facility, and they can be quite costly to repair or replace if neglected. Unlike walls, roofs, and floors (which are static and do not move), these building elements must remain capable of continual opening/closing. As such, frequent inspections of doors and windows are recommended to ensure that they remain functional, secure, and weather tight.

4.3.5.1 Inspection Criteria for Windows

Windows should be inspected regularly for the following:

- Loose-fitting frames
- Damaged frames and moldings
- Improperly fitting or broken sash
- Deteriorated putty
- Broken or worn sash cords
- Damaged weather stripping
- Inoperable, broken, or missing hardware and other operating parts
- Broken, cracked, or missing glass panes
- Peeling or cracked paint or protective coating

4.3.5.2 Inspection Criteria for Interior Doors

Doors should be inspected quarterly in accordance with the following criteria:

- Check for exposure conditions, specifically chemical attack (that is, is surface material resistant to process contamination?), impact exposure, staining and rust, surface deterioration, decay, splitting, operation or misuse of material, and extent of each.
- Check all previous repairs and patches for possible damage or deterioration.
- Check for loose or missing fasteners or anchorage.
- Check condition of wood frames for indications of wood rot, cracked or broken sections, warping, and finish failure.
- Check condition of metal frames and surfaces for indications of excessive corrosion, pitting, scaling, checking, warping, and finish loss.
- Check condition of gaskets and/or putty for deformation and deterioration, including cracking or missing areas that would allow glazing slippage.
- Check for cracked, broken, or missing glazing units, if applicable.
- Check for microorganism growth such as bacteria, molds, fungi, mildew, or dry rot on wood surfaces.
- Check for any insect damage (that is, termites or carpenter ants on wood surfaces).
- Check operation and condition of hardware for damage, inoperative condition, finish deterioration, or missing components.
- Check all door mechanisms, including door closure counterbalances, tracks, motors, gear boxes, and hold opens for proper operation, alignments, or balancing.

4.3.6 Coatings for Exterior Surfaces



Key Technical Point

The most effective way to conduct a thorough coatings condition assessment and detect coating degradation is through visual inspection.

Figure 4-1 illustrates reasons why visual inspections are the most suitable ways for assessing the condition of coating systems, as described in EPRI report 1003102, *Guideline on Nuclear Safety-Related Coatings, Revision 1 (Formerly TR-109937)* [3]. The overall advantages of performing visual inspections are derived by considering the nature of the coatings failures, basic premises regarding the application of the coating/paint, and the relative merits of visual inspections compared to other ways of testing.

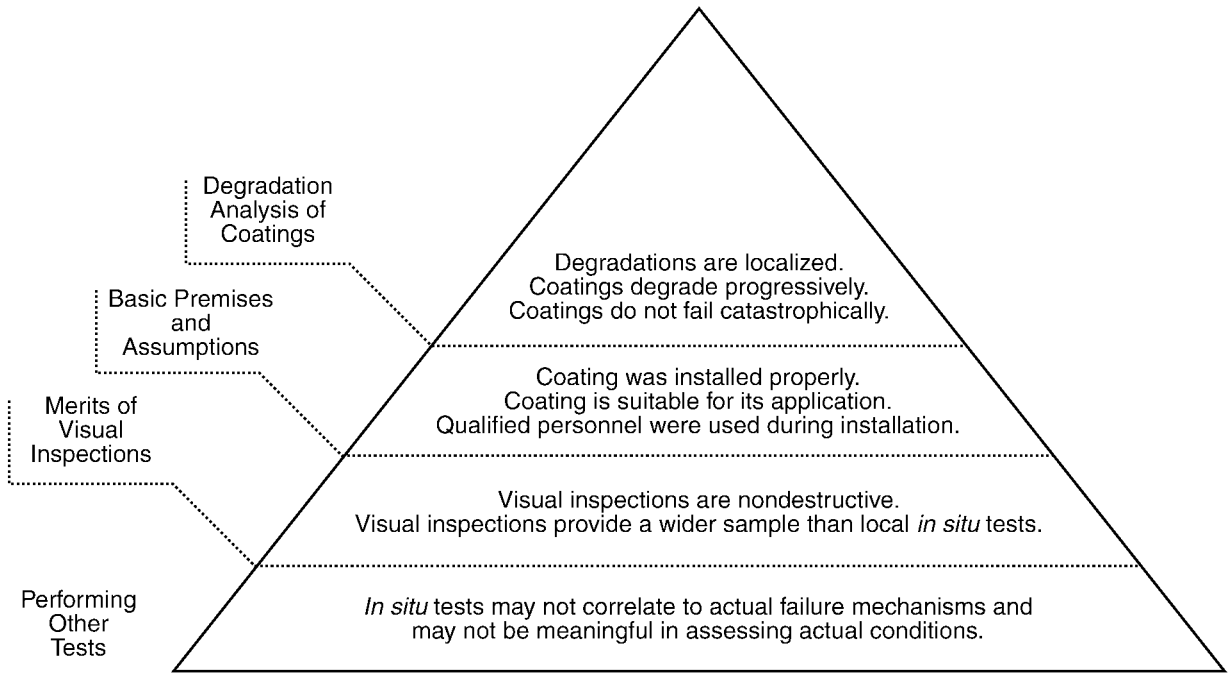


Figure 4-1
Advantages and Benefits of Visual Inspections for Coatings Condition Assessment

4.4 Inspection of Facility Systems

4.4.1 Water Distribution Systems

4.4.1.1 Fresh and Waste Water Plumbing Systems

Visual inspection of the piping systems and their respective fixtures, components, and instrumentation should be performed to identify evidence of any failure mechanisms that result in either leakage to the atmosphere or flow restriction. The location of leaks can be done by systematically inspecting exposed piping and valves and by examining walls, floors, and ceilings around concealed piping. In addition, gages, meters, and other water flow recording devices should be inspected for evidence of abnormal flow conditions. Inspection of piping and accessories should include the following criteria:

- Check the general appearance of the system.
- Note the buildup of ferrous oxide and cuprous oxide on piping surfaces or fitting bodies.
- Note pipe leakage locations at corroded sections, corroded or loose fittings, defective caulk joints, or flexible connections.
- Note piping distortion: bent, sagging, crimped, or crushed.
- Check piping expansion joints for proper operation: no leaks or loose fasteners.

- Check pipe supports and hangers for defects: loose or missing fasteners, improper alignment, or improper allowance for expansion.
- Record defects in piping insulation: missing, damaged, or wet.
- Check wall and floor pipe penetrations for defects (missing seal, improper fire-rating seal, lack of required flange cover or escutcheon).
- Note any valve stem leakage: improper packing adjustment or worn or missing packing.
- Check valves for damage: cracked housing or bent stem.
- Check all terminal units: physical damage, leakage, or loose fasteners.
- Check general pressure, temperature, and delivery rate at terminal fixtures.
- Check instrumentation: missing, inoperative, or illegible.

Valves and faucets should visually inspected to identify evidence of any of the failure mechanisms described in Section 3 of this report that result in either leakage to the atmosphere or flow restriction. Valve inspections can also include checking the following:

- Check operability of manually and motor-operated valves
- Check for evidence of excessive vibration or noise
- Check for evidence of water hammer when the valve is operated
- Check for oil leakage

Like valves, pumps should be visually inspected to identify evidence of any of the failure mechanisms described in Section 3 of this report that result in either leakage to the atmosphere or inadequate flow rate and discharge pressure. Pump inspection can also include checking the following:

- Verify flow-through unit.
- Monitor flow gauges. Check reading against rating and check defects.
- Monitor discharge head gauge. Check reading against rating and check defects.
- Check pump for excessive vibration and noise.
- Check operation of pressure and level controls: proper pump cut in and cut out.
- Inspect pump housing for stress cracks, corrosion, and other physical damage.
- Check pump mounts for loose, damaged, or missing fasteners.
- Check pump packing and seals for leakage.
- Check pump shafting for wear.
- Note condition of lubrication of pump bearings.
- Check coupling for wear, damage, or loose fasteners.
- Check coupling for leakage.

- Check coupling guard: present and secure.
- Check pipe fittings at pump connection for stress and leakage.
- Check all piping and fittings within 10 ft of pump for damaged or missing support and loose or missing fasteners.
- Inspect piping and fittings for leaks and corrosion.
- Check that insulation for pumps, pipes, and fittings is properly installed.
- Note level and pressure in expansion tank. Check reading against rating and check defects.
- Check exterior of expansion tank for corrosion and leaks.
- Check instrumentation: missing, inoperative, or illegible.
- Check bearing temperature, noise, and/or vibration.

4.4.1.2 Fire Protection Systems

Hose cabinets and related components. Inspection criteria for hose cabinets and related components (such as fittings, valves, and hoses) installed in standpipe systems for fire protection that should be considered are the following:

- Note general condition of cabinet. Record other abnormalities such as physical damage, and broken and missing glass.
- Note any missing components, such as hoses, racks, wrenches, or nozzles.
- Inspect pipe and valve inside cabinet. Note any corrosion or leakage.
- Check rack for damage, smooth operation.
- Note any physical damage to the hose, such as cracks, tears, or fraying.

Piping and related distribution components. Inspection criteria for piping and related distribution components (such as fittings, valves, hangers, and insulation) for all fire protection water/gas distribution systems that should be considered are the following:

- Check general appearance of system.
- Note buildup of ferrous oxide and cuprous oxide on piping surfaces.
- Note pipe leakage locations at corroded section, corroded or loose fittings, or defective caulk joints.
- Note piping distortion: bent, sagging, crimped, or crushed.
- Check piping expansion joints for proper operation: no leaks or loose fasteners.
- Check pipe supports and hangers for defects: loose, missing fasteners; improper alignment; improper allowance for expansion.
- Record defects in piping insulation: missing, damaged, or wet.

- Check wall and floor pipe penetrations for defects: missing seal, improper fire rating seal, lack of required flange cover or escutcheon.
- Note any valve stem leakage: improper packing adjustment or worn or missing packing.
- Check valves for damage: cracked housing or bent stem.
- Note general condition of instrument casings. Record other abnormalities such as physical damage and broken and missing glass.
- Note any missing components.
- Report instruments that are inoperative, illegible, or obviously inaccurate.
- Report system sprinklers and nozzles that are missing, leaking, corroded, or otherwise damaged.

Additional guidance regarding inspections of fire protection system components is provided in EPRI report 1006756, *Fire Protection Equipment and Surveillance Optimization and Maintenance Guide* [4].

4.4.1.3 Toilets, Lavatories, and Accessories

Inspection of toilets, lavatories, and accessories should include the following:

- Inspect lavatories for chips and cracks.
- Check that all faucets are functioning properly and without leaks. Check strainers for foreign objects.
- Check stopper in sink outlet for leak tightness.
- Check all angle valves and operate them to ensure that they are functional.
- Check remaining porcelain fixtures, such as urinals and water closets, for chips and cracks.
- Operate all flushing devices to ensure that they are working without leaks.
- Operate all shower valves and ensure that the heads are in good working order. Ensure that all openings in the showerhead are open.
- Check ceramic tile walls and floors to see if special cleaning is required, tiles need resurfacing, or regrouting is required.
- Check shower drain and pan to ensure that it is in place and to determine if repairs are needed.

4.4.1.4 Sewage Ejectors

Inspection of sewage ejectors should include the following:

- Check ejector for proper operating level and pressure.
- Note any leakage in ejector, piping, and fittings.

- Inspect ejector exterior for stress bulges or cracks, corrosion, or other physical damage.
- Check ejector supports for loose, damaged, or missing fasteners.

4.4.1.5 Storage Tanks

Inspection criteria for liquid storage tanks and related components (such as fittings, valves, floats, sight glasses, hangers, and insulation) installed as part of a building/facility utility generation and/or water distribution system that should be considered are the following:

- Check tank for proper operating level and pressure.
- Flush tank drain and check for contamination in effluent.
- Cycle relief valve (pressurized tanks only), check for proper reseating.
- Check that proper level/pressure are quickly restored.
- Note any leakage in tank, piping, and fittings.
- Inspect tank exterior for stress cracks, corrosion, and other physical damage.
- Check tank supports for loose, damaged, and missing fasteners.
- Check pipe fittings at tank connection for stress and leakage.
- Check that tank insulation is properly installed.
- Inspect tank foundations for signs of cracking, spalling, chipping, and for any exposed concrete foundation reinforcement.

4.4.1.6 Tanks and Sumps

Inspection criteria for collection/expansion tanks, sumps, and related components (such as fittings, valves, floats, sight glasses, hangers, and insulation) in building/facility utility generation and water distribution systems, and their related drainage, waste, and venting systems that should be considered are the following:

- Check tank for proper operating level and pressure.
- Flush tank drain and check for contamination in effluent.
- Cycle relief valve (pressurized tanks only), check for proper reseating.
- Check that proper level and pressure are quickly restored.
- Note any leakage in tank, piping, and fittings.
- Inspect tank exterior for stress cracks, corrosion, and other physical damage.
- Check tank supports for loose, damaged, and missing fasteners.
- Check pipe fittings at tank connection for stress and leakage.
- Check that tank insulation is properly installed.

4.4.1.7 Water Conditioners

Inspection criteria for water softeners and related components (such as brine tanks, fittings, valves, and floats) installed as part of a building's domestic water supply that should be considered are the following:

- Check brine tank for proper operating level and pressure.
- Flush brine tank drain and check for contamination in effluent.
- Inspect softener exterior for stress cracks, corrosion, and other physical damage.
- Note any leakage in softener and brine tank.
- Check softener supports for loose, damaged, and missing fasteners.
- Check pipe fittings at softener connection for stress and leakage.

4.4.2 Heating, Ventilating, and Air Conditioning Systems

4.4.2.1 Duct and Air Transport Systems



Key O&M Cost Point

A major source of trouble in duct systems, often resulting in the complete unbalancing of the system, is tampering with dampers and grills by unauthorized persons.

Inspection of duct systems should be performed to ensure that there are no leaks, that the air flow, pressure, and temperature are within design limits, and that there is no evidence of system component wear or failure (as noted in Section 3 of this report).

Ductwork and related components. General inspection of ductwork and related components (such as fittings, hangers, and insulation) installed as part of an HVAC system that should be considered are the following:

- Examine exposed ductwork.
- Note any unusual noise or vibration.
- Inspect duct and connections for cracks, corrosion, other physical damage, and leakage.
- Examine access plates and doors. Note corrosion, leakage, and loose or missing fasteners.
- Check dampers and operators for proper operation.
- Check insulation for loose or missing sections, damage, and wetness.
- Check supports for corrosion, damaged, and loose or missing fasteners.
- Check wall penetrations for proper fire protection: sealing and fire dampers.
- Check filter plenums for frame corrosion, loose filter holders, and other defects.
- Check air inlet and outlet devices for corrosion and damage.

Fans and blowers. The extent of servicing depends on the severity of operation and location of the unit. Fans operating under dusty conditions or in indoor locations or corrosive atmospheres require more frequent attention than those handling clean air in a dry location. Visual inspection of these components should be performed to check for the following:

- Excessive vibration
- Lubricant level leaks
- Loose screws and fastening hardware
- Proper tension and belt drives
- Bearing operation temperatures
- Signs of corrosion
- Axial clearance of each centrifugal fan

Dampers and louvers. Dampers are used most often in duct systems. Their purpose is to control air direction and volume. Facilities maintenance personnel should be aware of the location of all dampers in a system. Personnel should periodically check the operation of the dampers and louvers to ensure that they are able to open and close. They should be visually inspected to detect any evidence of physical deformation, corrosion, or missing and broken parts.

Expansion and construction joints. Table 4-6 provides an inspection plan for expansion and construction joints.

Table 4-6
Inspection Criteria for Expansion and Construction Joints [1]

Monthly Inspection
• Check for leaks. • Inspect supports. • Ensure that operating conditions do not exceed temperature and pressure ratings. • Check for excessive vibration and noise.
Annual Inspection
• General: look for signs of erosion, corrosion, wear, deposits, and binding on mechanical slip joints. • Alignment: check to be sure that pipes are in alignment. • Packing: adjust or replace packing as required to prevent leaks and ensure free-working joint. Maintain the packing material and its installation in accordance with the manufacturer's instructions. • Travel: check for flange-to-flange distance of the joint, first when cold, then when hot. Compare the findings with the travel limit shown on the manufacturer's data. A change in slip travel can indicate a slippage in the anchorage and/or pipe guide. • Bellow-type joints: inspect for alignment, fatigue, corrosion, and erosion. Check the travel distance of the joint under both cold and hot conditions, and compare the findings with the manufacturer's instructions.

Anchors. Quarterly, inspect anchors for corrosion, breaks, and shifting. Ensure that the anchors are holding and that the walls and footings near anchors do not show distress cracks. Ensure that the bolts, turnbuckles, wire ropes, and other stressed members give no sign of possible early failure.

Hangers and supports. Quarterly, inspect hangers and supports. Check for corrosion, wear, and failed parts. Ensure that all supports are in line with pipe and tracking tube, that supporting rollers turn freely, that each hanger carries its share of the load, and that there are no signs of possible early failure of any stressed member.

Traps, drains, and vents. Test all traps for correct operation monthly. Annually inspect for the following:

- Accumulation of foreign matter
- Plugging of orifices, valves, and vents
- Cracked, corroded, broken, loose, worn, or defective parts
- Excessive wear, grooving, and wire drawing of valves and seats
- Defective bells, buckets, or floats
- Leaky vessels and pipes
- Defective bypass valves

Air vents. At least once a year, inspect air vents for cleanliness, signs of corrosion of metallic parts, and physical damage that may restrict air flow.

4.4.2.2 Heating Systems

Hot-water systems. Each radiation unit should be checked periodically to ensure that air has not accumulated in the unit. The units should also be visually inspected for evidence of corrosion or scale deposits.

Pressure-atomizing burners. In general, burners should be inspected regularly for any evidence of mechanical, electrical, or combustion-related failure. If there is evidence of mechanical problems, check all valves on suction and feed lines to be sure that they are open, check the supply of the oil tank, check the vacuum on the suction line, check the lines for obstructions, check the viscosity of the oil, and check for leaks. The burners should also be visually inspected for any evidence of unclean burning, excessive smoke, or vapors.

Gas-fired units. Inspection can include lubrication of the motor and evidence of any soot buildup in the heat exchanger tubes.

Oil-fired units. Inspect oil-fired units frequently to ensure that the equipment is clean because accumulations of carbon and soot can cause fires. After cleaning burner pots, check fuel line connections for leaks. Visually inspect the general condition and cleanliness of the burner pilot assemblies. Check the pot for warped or deformed surfaces and burned-out sections, which can

cause loose connections and dangerous leaks. Check the automatic draft meter for defective hinge action and for warped surfaces in all working parts.

Electric heaters. Electric heaters should be visually inspected to check all electrical connections for worn or damaged parts and wires for frayed surfaces. Check and calibrate the thermostat according to the manufacturer's instructions. Check the operation of the safety switch on portable units. Check the safety light, which indicates when the unit is operating, and replace any burned-out bulbs. Check all fuse clips and wire connections for tightness. Check the heating units for pitting and for broken parts. Check inner surfaces for corrosion, rust, and wear. Inspect the heat chamber for collection of dust and dirt. Check the safety guard for proper operating conditions.

Steam units. Check unit heaters frequently if they are operated in a location where the air is dusty or sooty or where corrosive fumes or oil sprays are present. The motor should be inspected for proper operation and cleanliness. Ensure that the fan assembly is in its proper position in the shaft, and that the hub set screws are tight. Check for loose fan blades, cracks, and excessive vibration. During each inspection, wipe fan blades clean. Periodically, check all fastenings on the unit for looseness or wear, which can cause excessive noise and vibration. Check the operation of the trap if the heater fails to deliver the proper amount of heat. Check the operation of the float linkages if they do not operate freely. Check thermostats for proper operation.

Fuel-fired boilers. Inspection criteria for fuel-fired boilers and related components (such as fittings, valves, strainers, and insulation) installed for heating steam generation that should be considered include the following:

- Check temperature, pressure, and level instrumentation for proper operation. Note any defects, inaccuracies, illegibility, or missing components.
- Observe unit through an operating cycle. Note proper purging on startup and shutdown.
- Note any unusual noise or vibration in the boiler casing. Check for pulsations.
- Check for unusual odors or flame color, which indicate poor combustion.
- Inspect outer casing for stress cracks, corrosion, and other physical damage.
- Check base of casing for signs of leakage.
- Check manholes and hand holes for corrosion and leakage.
- Check all piping, fittings, and flanges within 10 ft of boiler for corrosion, leakage, loose or missing fasteners, and physical abuse.
- Check insulation for loose or missing sections, damage, or wetness.
- Cycle pressure relief valves and check for proper reseating.
- Examine valves for packing leakage and excessive corrosion. Note any damage to operating mechanisms.
- Check boiler and piping supports for loose, damaged, or missing fasteners.
- Check integral fan housings for corrosion, leakage, and damage.
- Check fan motor for proper operation. Note any corrosion or physical damage.

- Note any unusual noise or excessive vibration in the fan/motor assembly.
- Check breaching, chimney, and stack for excessive corrosion, loose fasteners, or leakage.
- Note any damage in air flow dampers and linkage.
- Examine exposed parts of economizer, superheater, and soot blowers for any signs of leakage, damage, or loose or missing fasteners.
- Examine integral equipment controls and wiring.
- Note any inoperative motor starters.
- Check conduit, control housings, and panels for corrosion or leakage.
- Note any controls that have been bypassed for operation.

Deaerators. Inspection criteria for deaerators and related components (such as fittings, valves, strainers, hangers, and insulation) included in heating steam and condensate return systems that should be considered are the following:

- Check temperature, pressure, and level instruments for proper operation. Note any damage, inaccuracies, illegibility, or missing components.
- Observe unit through a pumping cycle. Check for proper level cut in and cut out.
- Note any unusual noise or vibration.
- Drain some water from unit. Check effluent for sediment.
- Inspect shell exterior for stress cracks, corrosion, and other physical damage.
- Check base of unit for signs of leakage.
- Check manholes and hand holes for corrosion and leakage.
- Check all piping, fittings, and flanges within 10 ft of unit for corrosion, leakage, loose or missing fasteners, or physical abuse.
- Check insulation for loose or missing sections, damage, or wetness.
- Examine valves for packing leakage and excessive corrosion. Note any damage to operating mechanisms.
- Check deaerator and piping supports for loose, damaged, or missing fasteners.
- Examine integral equipment controls and wiring.
- Note any inoperative motor starters.
- Check conduit, control housings, and panels for corrosion or leakage.
- Note any controls that have been bypassed for operation.

4.4.2.3 Water Heaters

Inspect water heaters for any evidence of leaks in faucets, valves, piping, flues, tanks, heaters, and accessories. Check for evidence of missing or broken insulation. Check the control device, which automatically regulates water temperature. Check for evidence of water leaks at the control devices. Visually observe the operation of the gages. Examine water temperature regulators and thermostatic devices for performance and defects. Check the accuracy of thermostats and temperature regulators with dry-bulb mercury thermometers.

Gas hot-water heaters. Make frequent checks of the gas burner and controls. Examine the gas pilot and adjust the pilot flame when it is too high. Check the operation of the automatic controls for a full operation cycle. Examine the water temperature regulator, solenoid and motorized valves, gas pressure regulator, pilot flame failure device, and automatic gas shutoff valve control by excess temperature of hot water. Check the draft diverter for any evidence of clogging.

Oil-fired heaters. Inspect often to ensure that the equipment is clean and that connections are tight. Check the fuel line connections for leaks. Ensure that the supply pipe is always clean and that there is no oil on its outer surface. This applies to all the piping and tubing, starting at the oil tank and reservoir and extending to the burner.

Electric heaters. Inspect the electrical heating elements, wiring, and controls. Observe the operation of the automatic controls for a complete operation cycle and adjust them when they are not satisfactory. Check the voltage when the heating output is not adequate. Inspect electrical contacts that are not enclosed in a dust-type cover to ensure that there is no accumulation of dust or lint that could prevent them from making a good contact.

4.4.2.4 Pneumatic Systems

Table 4-7 provides an inspection plan for reciprocating compressors.

Table 4-7
Inspection Criteria for Reciprocating Compressors [1]

Daily Inspection
• Check for unusual noise or vibration. • Check for abnormal pressure or temperatures of compressed air, cooling water, and lubricating oil. • Check for proper operation. • Check for hot stuffing box. • Check for hot bearings. • Check for correct lubricating oil levels.
Quarterly Inspection
• Inspect compressor valves for wear, dirt, and proper seating. • Check operation of all safety valves. • Check packing for wear and piston rods for scoring. • Examine crank case for sludge accumulation. • Check cylinder heads for tightness. • Inspect connecting rods and crossheads for wear. • Inspect bearings for wear and dirt. • Check operation of lubrication and oil cups.
Annual Inspection
• Check cylinders for wear, scoring, corrosion, and dirt. • Inspect pistons for leakage, wear, and scoring. Check the security of the piston rod. Check head clearances. • Examine piston rings for damage, wear, tightness, and dirt. • Check piston rods wear at packing glands and security to crosshead in piston. • Inspect crank case and crank shaft bearing for wear and proper operation. • Check crow heads, crow head guides, wedges, and pins for wear and proper operation. • Check flywheel for security to shaft. Inspect flywheel bearing for wear and dirt. • Check alignment of compressor with drive.

Table 4-8 provides an inspection plan for rotary sliding vane compressors.

Table 4-8
Inspection Criteria for Rotary Sliding Vane Compressors [1]

Daily Inspection
• Check for unusual noise or vibration. • Check for abnormal pressure or temperatures of compressed air, cooling water, and lubricating oil. • Check for evidence of motor overheating. • Check for hot stuffing box. • Check for hot bearings. • Check for correct lubricating oil levels.
Semiannual Inspection
• Check the alignment of the compressor to the drive. On two-stage units, also check the alignment of the outboard compressor to the inboard one. • Check the condition of packing.
Annual Inspection
• Check bearings for wear and dirt. • Check shaft for wear of seals. • Examine the mechanical seals for damage. • Remove rotor blades and inspect for wear. • Examine cylinder board for wear and scoring. • Examine all gaskets for damage.

Table 4-9 provides an inspection plan for rotary twin lobe compressors.

Table 4-9
Inspection Criteria for Rotary Twin Lobe Compressors [1]

Daily Inspection
• Check for evidence of abnormal suction. • Inspect discharge pressures and oil temperature pressure. • Check for unusual noise or vibration. • Check for hot bearings. • Check for motor overheating. • Check for oil leaks.
Annual Inspection
• Check for corrosion or erosion of parts. • Check for proper clearances. • Check for correct alignment. • Check for worn or broken timing gears. • Inspect timing gear setting. • Inspect operating setting of relief valves. • Check for shaft or wear at seals.

Table 4-10 provides an inspection plan for rotary liquid piston compressors.

Table 4-10
Inspection Criteria for Rotary Liquid Piston Compressors [1]

Daily Inspection
• Check for abnormal discharge pressures. • Check for unusual noise or vibration. • Check for motor overheating. • Check for hot bearings. • Check for correct sealing water flow and pressure.
Semiannual Inspection
• Check the alignment of the compressor to the drive. • Examine packing for wear and shaft for scoring at packing or seals. • Check setting and operation of the relief valve.
Annual Inspection
• Check bearings for wear and dirt. • Check for corrosion or erosion of parts. • Correct clearances. • Compressor internals for scale deposits. • Examine all gaskets for damage. • Mechanical seals for damage.

Table 4-11 provides an inspection plan for dynamic compressors.

Table 4-11
Inspection Criteria for Dynamic Compressors [1]

Daily Inspection
• Check for unusual noise or vibration. • Check for abnormal pressure or temperatures of compressed air, cooling water, and lubricating oil. • Check for evidence of motor overheating. • Check for proper operation of auxiliary oil pump. • Check for hot bearings. • Check for correct lubricating oil levels.
Semiannual Inspection
• Check the condition of the lubricant. • Check for deterioration of the oil and for presence of water in the oil. • Test all safety controls.
Annual Inspection
• Check journal and thrust bearings for wear. • Check alignment and coupling condition. • Examine compressor cases for corrosion and peeling paint. • Examine compressor belts and tighten if needed.

Intake filters. Inspect air filters once each month for sludge accumulations, clogged filter elements, and proper oil level.

Silencers. Semiannually, inspect the silencers for the following:

- Externally: corrosion and peeling paint
- Internally: corrosion and dirt accumulation
- Damaged gaskets

Intercoolers and aftercoolers. Table 4-12 provides an inspection plan for intercoolers and aftercoolers.

Table 4-12
Inspection Criteria for Intercoolers and Aftercoolers [1]

Daily Inspection
• Check for proper operation of the automatic controls and instruments. • Check for water leaks, temperature, and flow rate. • Check for deviations from normal temperature, or pressure drops across the cooler.
Semiannual Inspection
• Check for corrosion and peeling paint. • Check for setting and proper operation of relief valves. • Check for leakage and corrosion of manual and automatic valves.
Annual Inspection
• Check for corrosion and erosion of internal components, such as tubes, tube sheets, and baffles. • Check for leaking tubes. • Check for plugged tubes. • Check for scale deposits on tubes or shelves.

Separators. Inspect the separator once every six months for the following:

- Externally: rust, corrosion, and peeling paint
- Internally: corrosion and accumulation of dirt and oil
- Damaged gaskets

Traps. Table 4-13 provides an inspection plan for traps.

Table 4-13
Inspection Criteria for Traps [1]

Daily Inspection
• Check for operation of the trap drains. • Ensure that the trap is draining properly and is not blowing air.
Annual Inspection
• Check for corrosion and erosion of parts. • Check for worn valves or seats. • Check for defective floats for buckets. • Check for loose or damaged linkages.

Absorption-type air dryers. Table 4-14 provides an inspection plan for absorption-type air dryers.

Table 4-14
Inspection Criteria for Absorption-Type Air Dryers [1]

Daily Inspection
• Check for proper operation of instruments and drain traps, where provided. • Check for air or steam leaks.
Annual Inspection
• Inspect relief valves for proper operation. • Inspect dryer towers, piping, and valves for corrosion, rusting, and peeling paint. • Inspect desiccant bed for oil and dirt.

Refrigeration-type air dryers. Table 4-15 provides an inspection plan for refrigeration-type air dryers.

Table 4-15
Inspection Criteria for Refrigeration-Type Air Dryers [1]

Daily Inspection
• Inspect operation of the condensation drain. • Check for air leaks.
Quarterly Inspection
• Inspect condition of the filter cartridge. • Check for oil and dirt accumulations in the condensation collection chamber and condenser evaporator tube.

Compressed-air gas storage tanks. Table 4-16 provides an inspection plan for compressed-air gas storage tanks.

Table 4-16
Inspection Criteria for Compressed-Air Gas Storage Tanks [1]

Quarterly Inspection
• Check tank for proper operating level and pressure. • Note any leakage in tank, piping, and fittings. • Inspect tank exterior for stress cracks, corrosion, and other physical damage. • Check tank supports for loose, damaged, or missing fasteners. • Check pipe fittings at tank connection for stress or leakage. • Report any missing tanks or fittings. • Cycle relief valves; check proper reseating.

Small gasoline, diesel, or propane engines. Table 4-17 provides an inspection plan for these types of small engines.

Table 4-17
Inspection Criteria for Small Gasoline, Diesel, or Propane Engines [1]

Quarterly Inspection
• Observe operation of engine. • Note any unusual noise or vibration in the engine or accessories. • Note any leakage in engine, coolers, piping, and fittings. • Take sample of engine oil and have it tested for engine wear products. • Inspect engine housing for stress cracks, corrosion, or other physical damage. • Check engine mounts for loose, damaged, or missing fasteners. • Check pipe fittings at engine connection for stress or leakage. • Check intake filter for dirt infiltration. • Inspect exterior of coolers for damaged fins. • Check drive for misalignment. • Inspect battery charger and batteries for proper operation, physical damage, and general condition.

4.4.2.5 Steam Distribution Systems

Table 4-18 provides an inspection plan for steam distribution systems.

Table 4-18
Inspection Criteria for Steam Distribution Systems [1]

Monthly Inspection
• Check for leaks. • Check for damaged insulation. • Check for abnormal pressures and temperatures. • Check for abnormal pressure drops. • Check for vibration. • Check for correct operation of equipment, such as steam traps, pumps, pressure and temperature controllers, and strainers.
Annual Inspection
• Check for piping corrosion, leaks, loose joints; and damaged or missing supports. • Inspect condition of insulation and protective jacket. • Check for setting or shifting in position of poles, hangers, or other supports. • Check for leaky, corroded, or defective valves; packing glands, hand wheels, body flanges, and gaskets. • Inspect valve and meter pits for clogged vents, structural damage, missing covers, and accumulations of dust and dirt. • Inspect condition of flanged fittings. • Inspect condition of expansion joints. • Inspect condition of anchors, hangers, guides, and supports. • Inspect condition of steam traps, strainers, and moisture separators. • Inspect condition and calibration of pressure-reducing stations. • Inspect setting of relief safety valves. • Inspect condition and calibration of instrumentation. • Inspect condensate return piping.

4.4.2.6 High-Temperature Water Distribution Systems

Table 4-19 provides an inspection plan for high-temperature water distribution systems.

Table 4-19
Inspection Criteria for High-Temperature Water Distribution Systems [1]

Monthly Inspection
• Check for leaks. • Inspect traps, strainers, and dehumidifiers for proper operation and evidence of moisture and dirt. • Check for abnormal pressures: insufficient pressure indicates excessive leakage, line obstructions preceding a using station, clogged strainers, defective compressor operation or controls, or improper operation of pressure-reducing stations. Excessive pressure indicates malfunction of compressor control, improper setting or defective operation of the air receiver safety valve, or malfunction of the pressure-reducing stations. • Check for excessive pressure drops: an overload of the pipe line or a line unduly obstructed results in an excessive pressure drop. • Check for vibration: inadequate or defective supports and improper anchorage cause vibration. • Check for corrosion: protect the external surfaces of the air lines from corrosion by using corrosion-proof paint or adequate covering.
Annual Inspection
• Check for piping corrosion, leaks, loose joints, and damaged or missing supports. • Inspect condition of insulation and protective jacket. • Check for setting or shifting of poles, hangers, or other supports (by checking the grade of the line). • Check for leaky, corroded, or defective valves; packing glands, hand wheels, body flanges, and gaskets. • Check for valve and meter pits for clogged vents, structural damage, missing covers, and accumulations of dust and dirt. • Inspect condition of flanged fittings. • Inspect condition of expansion joints, if any. • Inspect condition of anchors, hangers, guides, and supports. • Inspect condition of traps, strainers, dehumidifiers, and moisture separators. • Inspect condition and adjustment of pressure-reducing stations. • Inspect setting of relief and safety valves. • Inspect condition and calibration of instrumentation. • Inspect condition of air receivers.

4.4.2.7 Instruments and Controls

Table 4-20 provides an inspection plan for instruments.

Table 4-20
Inspection Criteria for Instruments [1]

Daily Inspection
• Check all accessible instruments and gages for defects such as leaks, cracks, and broken glass bed pointers.
Annual Inspection
• Check for corrosion, deposits, binding, and mechanical defects of gages. • Check for ruptured or distorted pressure parts. • Check for incorrect calibration or adjustment. • Check for leaking pipes or meters. • Check for plugged internal passages. • Check for loose pointers. • Check for broken balance arm screws. • Check for broken or loose linkages. • Check for broken or damaged adjustment assemblies. • Check for dirt and dust. • Check for binding of moving parts. • Check for dirty gage movements. • Check for linkage pins binding. • Check for defective gage glass gaskets. • Check for gage valve packing leaks. • Check for worn pins or bushings. • Inspect mercury separation thermometers. • Check for temperature bulbs damaged by overheating. • Check for plugged piping or tubing and loose connections. • Check for mercury contamination. • Check for defective floats. • Inspect operation of clockwork mechanism and integrator.

Table 4-21 provides an inspection plan for controls.

Table 4-21
Inspection Criteria for Controls [1]

Daily Inspection
• Observe operation of controls. • Inspect for leaks and repair stuffing box leaks as soon as possible.
Annual Inspection
• Dismantle regulator valve and control mechanism; clean system components; and inspect for wear, corrosion, erosion, pitting, deposits, leaks, and mechanical defects. • Inspect all safety devices and warning signals for defects and observe for correct operation. • Check settings, adjustments, and operation of controls. • Observe operation of safety devices.

4.4.2.8 Air Conditioning Systems

Table 4-22 lists component-level inspection criteria for air conditioning systems.

Table 4-22
Inspection Criteria for Air Conditioning Systems [1]

System Component	Inspection Criteria
Compressors	• Check for dirt and dust accumulation. • Check for leakage of oil, water, or refrigerants. • Check for loose connections. • Check for loose or worn belts or parts. • Check for misalignment. • Check for excessive noise and vibration. • Check for incorrect suction and discharge pressure.
Motors, drive assemblies, and fans	• Check for dust, dirt, and graft accumulations. • Check for worn, loose, missing, or damaged connections and connectors. • Check for bent blades. • Check for worn or loose belts. • Check for unbalance and/or misalignment. • Check for excessive noise or vibration, end play of shafts. • Check for ineffective sound isolators. • Check for poor condition of motor windings and brushes.
Air ducts, dampers, registers, grills, louvers, and screens	• Check for soot, dirt, dust, and other deposits. • Check for leaks. • Check for broken, loose, or missing connections and parts. • Check for excessive vibration. • Check for material defects. • Check for defective operation of moveable parts. • Check for hinged parts failure. • Check for improper seasonal or operating settings of dampers. • Check for inadequate air distribution in branch circuits.
Wiring and electrical controls	• Check for loose connections. • Check for charred, frayed, broken, or wet insulation. • Check for short circuits. • Check for loose or weakened contact springs. • Check for worn, pitted, or corroded connections. • Check for defective operation. • Correct fuses and other deficiencies.
Steam and hot-water heating units	• Check for flow restriction and clogging. • Check for dirty heat-transfer surfaces. • Check for leaking. • Check for rust and corrosion. • Check for cracking resulting in leaks. • Check for loose connections and parts. • Check for physical deformation and bent fins. • Check for water hammer. • Check for defective or inoperable valves. • Check for below-normal temperature readings.

Table 4-22 (cont.)
Inspection Criteria for Air Conditioning Systems [1]

System Component	Inspection Criteria
Thermal insulation and vapor barriers	• Check for wet, damaged, or missing insulation or vapor barrier. • Check for open seams, breaks, missing sections. • Check for missing or loose fastening. • Check for material disintegration and loss of insulating capability.
Air filters	• Check for flow restriction from dust, grease, or other deposits. • Check for corrosion of metallic parts. • Check for physical deformation and bending.
Guards, casings, hangers, supports, platforms, and mounting	• Check for loose, broken, or missing parts. • Check for physical deformation. • Check for improper level. • Check for ineffective sound isolators. • Check for corrosion of metallic parts.
Temperature and humidity controls	• Check for loose connections. • Check for worn, dirty, pitted, or misaligned contacts. • Check for inaccuracy of thermostat and humidistats.
Electrical heating units	• Check for burned, pitted, or dirty electrical contacts. • Check for short-circuited sections of elements. • Check for low voltage in electrical circuits. • Check for dirty or corroded reflective, heat-transfer surfaces.
Pump units	• Check for accumulation of dust, dirt, and other deposits. • Check for corrosion of metallic parts. • Check for worn impeller and blades. • Check for shaft deformation or misalignment. • Check for cracks in casing.
Piping	• Check for cracks and corrosion. • Check for clogging and scaling causing flow restriction.
Water sprays and weirs	• Check for external scale and corrosion. • Check for cracks resulting in leaks. • Check for clogging of pipes and nozzles. • Check for improperly positioned spray nozzles, baffles, or eliminators to control spray drift. • Check for corrosion of metallic parts.
Shell- and tube-type condensers	• Check for cracks and corrosion of tubes. • Check for clogging and scaling of tubes and shell.
Cooling coils	• Check for cracks in coils resulting in loss of refrigerant. • Check for bent fins and other physical deformations. • Check for clogging and scaling of tube interior, restricting flow. • Check for corrosion or accumulation of dirt on fins.

Cooling towers. Inspection criteria for cooling towers and related components (such as fittings, valves, strainers, hangers, and insulation) installed in HVAC cooling service and distribution systems that should be considered are the following:

- Check temperature and level instrumentation for proper operation. Note any defects, inaccuracies, illegibility, or missing components.
- Check temperature and level readings. Validate consistency with load and refrigerant characteristics.
- Note any unusual noise or vibration in the tower.
- Inspect tower frame for cracks, corrosion, wood rot, and other physical damage.
- Check basin for corrosion and leakage.
- Check access plates for signs of leakage.
- Check basin level control for damage or defects.
- Check tower fill and eliminators for damage, missing sections, or collapse.
- Inspect fan assembly for cracks, corrosion, or other physical damage.
- Check tower top for missing or blocked distribution nozzles and missing or damaged inspection covers.
- Check all piping, fittings, and flanges within 10 ft of the tower for corrosion, leakage, loose or missing fasteners, and physical abuse.
- Examine valves for leakage and excessive corrosion. Note any damage to operating mechanisms.
- Check tower and piping supports for loose, damaged, or missing fasteners.
- Examine integral equipment controls and wiring.
- Note any inoperative motor starters.
- Check conduit, control housings, and panels for corrosion or leakage.
- Note any controls that have been bypassed for operation.

4.4.3 Electrical Systems

4.4.3.1 Electrical Distribution Systems

Wiring. Particular attention should be given to electrical wiring in a building. Conditions such as loose wiring, poor connections, bare conductors, defective convenience outlets and switches, and defective attachment cords should be identified and corrected immediately. Wiring systems

should be checked frequently to reduce fire hazards, correct defective wiring, and eliminate oversized lamps and overloaded circuits. Items that should be checked when visually inspecting wires and cables are the following:

- Dirty, poor ventilation, detrimental ambient conditions, presence of moisture, grease, oil, and chemical fumes.
- Improper or unauthorized connections and dangerous temporary connections.
- Damaged wiring devices, defective insulators, cleats, and cable supports, broken or missing parts, or exposed live parts.
- Excessive cable sag and vibration, crowded cable spacing, and excessive number of conductors in conduit and raceways.
- Evidence of overheating, grounds, and short circuits; overheated splices and damaged or defective insulation.
- Need for painting of noncurrent-carrying parts subject to corrosion.
- Unsafe, unreliable cable and wire to lighting and power panels.
- Fuses, switches, and other sources of discontinuity installed in the neutral ground wire of ac systems.

Ducts and trays. All systems of the underfloor duct type require checks for evidence of oil and water. Entrances and fittings should be checked and corrected as necessary to prevent entrance of liquids, insects, and rodents. External heat and heat caused by overloaded circuits cause cracking of insulation and drying of tape splices that, in turn, allow moisture to enter with resultant grounding. Underfloor conduits and duct systems should be kept sufficiently clear of electrical and hot-water floor-heating systems to prevent undue heating of the enclosures.

Fuses, circuit breakers, and switchgear. A fuse consists of many parts, some current carrying and some noncurrent carrying, all subject to atmospheric conditions. The frequency of inspection is necessarily a function of the conditions at a given fuse location. Some key inspection criteria for fuses are the following:

- Inspect insulators for breaks, cracks, or burns.
- Inspect contact surfaces for pitting, burning, alignment, and pressure.
- Examine fuse holder before installing a renewable element for excessive erosion of the inside of the fuse tube, tracking, and excessive dirt on the outside of the fuse tube.
- Ensure that bolts, nuts, washers, pins, and terminal connectors are in place and in good condition.

Circuit breaker failures can be minimized by frequent visual inspections. When inspecting circuit breakers in service, unusual conditions that should serve as a warning that maintenance is needed are the following:

- Low bushing oil gage reading
- Low breaker tank oil level

- Oil or air leaks
- Broken porcelain
- Loose hardware
- Broken or missing cotter pins
- Air supply compressor running excessively
- Deenergized cabinet heaters
- Excessive corrosion or rust
- Loose gaskets on covers
- Unusual noise, smoke, or temperatures

Switches should be inspected for evidence of heating, oxidation, and adequate capacity. Heating of switches can be attributed to oxidation, overload, unbalanced loading, and exterior forces such as steam lines, furnaces, and poor ventilation. Loose or oxidized screws, nuts, and fittings in poor contact pressure should generally be investigated immediately at any indication of undue heating.

Cabinets. Distribution panels or cabinets should be visually inspected for rust, dirt, oil, debris, moisture, loose connections, and unauthorized or nonstandard attachments. All disconnecting devices should remain labeled to indicate circuit or feeder designation, and the unit should be labeled to show all current and voltage characteristics.

4.4.3.2 Lighting Systems

Visual inspections and operational checks should be performed on lighting systems to ensure that they are functional and pose no electrical hazards. Routine visual inspections and operational checks should be performed in accordance with the guidance provided in Table 4-23.

Table 4-23
Inspection of Lighting System Components [1]

Lighting System Component	Inspection Criteria
Lighting fixtures	• Ensure that they are adequately supported, secure, and properly located. • Ensure that they are suitable for their intended application and location. • Check for cracked or broken luminaries and fixture parts, missing pull cords, and metal pull chains not provided with insulating links. • Check for evidence of overheating, undersized, or other damage to sockets, and exposed or damaged connecting wiring.
Lamps	• Check for oversized, blistering, loose base, thermal cracks from contact with fixture, bare lamps in hazardous locations, poor socket lamp connections, and improper types for special applications. • Check for proper operation of fluorescent fixtures, giving no indication of poor burning and starting or loud humming.
Switches	• Check for evidence of defective operation, broken or missing parts, and arcing noises.
Convenience outlets	• Check for dirty, inadequate, or defective contacts. • Check for evidence or overheating. • Check for evidence or overloading on multiple sockets servicing lamps or appliances, and lack of grounding terminal.
Cords, cord extensions	• Check for evidence of poor insulation, twisting, splices, exposed to damage underfoot, lying on floor or across heated surfaces or lamps. • Ensure that lamp types used for portable extensions are not subjected to moisture, oil, and grease. • Check for plugs with cracks, breaks, loose connections, wires improperly attached and in danger of pulling away from plug when removing from outlet, missing protective cover on male ends, and no grounding terminal or ground wire with clamp.
Lighting voltage	• Spot measurement at fixture and lighting outlets to indicate measured voltage in excess of 5% of nominal lamp voltages. • Ensure that there are no unauthorized connections of electrical equipment. • Check for interference with branch circuits for power and lighting, such as excessive light flicker, from motor starting or stopping. • Check for excessive voltage dips causing fluorescent and mercury lamps to drop out.
Illumination levels	• Identify poor ambient conditions such as dirty walls and ceilings. • Spot measurement of light levels using accurate footcandle meter to indicate deprecation of 20–25% of level obtainable from clean fixtures and new lamps seasoned for 100 hours.

4.4.3.3 Motors

Motors should be inspected regularly when the motor is running and while it is not in operation and is electrically disconnected. Table 4-24 describes items that should be checked during a typical running inspection.

Table 4-24
Inspection Criteria for Running Motors [1]

Inspection Area	Inspection Criteria
Operator records	• Check for evidence of motor or generator overload, low power factor of load, excessive variations in bearing temperature, and operating difficulties.
Exposure	• Check for unsafe accessibility for maintenance of instrumentation. • Check for exposure to physical or other damage from normal plant functions, processes, traffic, and radiant heat. • Check for inadequate personnel guards, fences, insufficient, missing or illegible sings, identification, or operating instructions.
Housekeeping	• Check for dust, dirt, airborne grit, sand, dripping oil, water, other fluids, vapors, rust, and corrosion. • Check for peeling, scratches, abrasions, and other damage to painted surfaces.
Operation	• Check for noisy, unbalanced, rubbing, excessive vibration, and rattling parts.
Structural supports	• Check for inadequate, cracks, and settlement. • Check for defective or inadequate vibration pads, shock mounts, dampers, and loose, dirty, and corroded bolts and fittings.
Ventilation	• Check for dirty, inadequate amount of air passing through machine. • Check for dirty, clogged, stator-iron air slots causing excessive temperature.
Motor and generator leads	• Check for exposed bare conductors. • Check for frayed, cracked, or peeled insulation. • Check for poor taping. • Check for moisture, paint, oil, grease, vibration, abrasions, and breaks in insulation at entrance to conduit or machines. • Check for arcs, burns, overheated, or inadequate terminal connections. • Check for lack of resiliency, lack of life, or dried-out insulation. • Check for exposure to physical damage, traffic, water, heat, for semipermanent, temporary, or emergency connections.
Bearings	• Check for improper lubrication or improper oil level in oil gages. • Check for incorrectly reading gages, noisy bearings, or overheated bearing caps or housings.

Table 4-24 (cont.)
Inspection Criteria for Running Motors [1]

Inspection Area	Inspection Criteria
Collector rings, commutators, and brushes	• Check for excessive sparking, surface dirt, or grease. • Check for sparking or excessive brush movement caused by eccentricity, sprung shaft, worn bearings, high bars of mica, surface scratches, or roughness. • Check for endplay resulting from magnetic-center hunting of rotor. • Check for inadequate brush freedom. • Check for nonuniform brush wear. • Check for poor commutation. • Check for improper brushes or incorrect brush pressures.
Starters, motor controllers, rheostats, and associated switches	• Check for damaged or defective insulation or loose laminations. • Check for defective heater or resistance elements, worn contacts, shorts between contacts, arcing, grounds, loose connections, and burned or corroded contacts.
Protective equipment	• Check for dirt, signs of arcing, symptoms of faulty operation, improper condition of contacts, burned-out pilot lamps, or burned-out fuses.

Table 4-25 describes items that should be checked during a typical shutdown inspection.

Table 4-25
Inspection Criteria for Motors After Being Shut Down [1]

Inspection Area	Inspection Criteria
Stators	• Check for dirt, debris, or grease. • Check for coils not firmly set in slots. • Check for burns, tears, aging, embrittlement, or moisture in insulation. • Check for clogged air slots. • Check for rubbing, corrosion, or loose laminations of stator iron. • Check for charred or broken slot wedges. • Check for abrasion of insulation or chafing in slots. • Check for signs of arcing or ground.
Rotors	• Check for difficulty turning, rubbing, excessive bearing friction, end play, overheating, looseness of windings, or charred wedges. • Check for broken, cracked, or loosely welded or soldered rotor bars or joints. • Check for cracked end rings in squirrel-cage motors. • Check for loose field spools and deteriorated leads and connections in synchronous motors. • Check for deteriorated insulation in wound motors.
Rotor-stator gaps	• Check gaps on 5 HP or larger induction motors, particularly of the sleeve-bearing type. Where practical, measure and record gaps on the load, pulley, or gear end of the motor. Measure at two rotor positions, 180 degrees apart, four points for each rotor position. If there is more than 10% variation in gaps, arrange for realignment.
Mechanical parts	• Check for corrosion, improper lubrication, misalignment, end play, interference, or inadequate chain or belt tension.
Insulation resistance	• Test insulation resistance of motor and generator windings. Insulation resistance values are arbitrary and should be correlated with operating conditions, exposure to moisture, metallic dust, age, length of time in service, severity of service, and maintenance levels.

4.4.3.4 Batteries

Batteries used in vehicles, generators, backup and uninterruptible power supplies should be inspected on a periodic basis in order to ensure optimum efficiency. Items that should be checked during periodic inspections are the following:

- Evidence of proper charging
- Water level
- Cleanliness
- Operating temperatures
- Evidence of shorts, corrosion, or physical damage
- Evidence of leaking from cracks in the battery casing

4.4.3.5 Transformers

Table 4-26 describes items that should be checked during inspection of transformers while in the deenergized state.

Table 4-26
Inspection Criteria for Deenergized Transformers [1]

Inspection Area	Inspection Criteria
Bushings and insulators	• Check for cracks, checks, chips, or breaks of insulators and porcelain parts. • Check for evidence of flashover streaks. • Check for severe cracks, chipped cement, or indication of leakage around bases of joints of metal to porcelain parts at terminal and transformer ends. • Check for mechanical deficiencies, looseness, corrosion, or damage to cable clamps at terminal ends. • Check for improper oil level in oil-filled bushings. • Check for heating evidenced by discoloration, and corrosion indicated by blue, green, white, or brown corrosion products on metallic portions of main and ground terminals, including terminal board and grounding connections inside transformer case. • Check for evidence of overheating or flashover fusing of pipe, bar copper, and connections. • Check for broken, burned, or corroded cable connections, or missing strands of cable elements.
Enclosure and cases	• Check for signs of moisture inside the cover. • Check for plugged breathers, inactive desiccant, or enclosure leakage.
Coils and cores	• Check for evidence of deficiencies, dirt, and sludge on interior.
Bushing-type instrument transformers	• Check for indications of deteriorated insulation, overheating evidenced by excessive discoloration of terminals and other visible copper, or physical strains indicated by bent or distorted members. • Check for corrosion and loose connections of terminals (including secondary leads). • Check for rust, corrosion, or other deterioration of conduit and associated fittings.
Load ratio control apparatus	• Inspect in accordance with the manufacturer's recommendations.
Forced-air fans and fan controls	• Check for defective bearings, inadequate lubrication, presence of dirt; bent or broken fan blades and guards; lack of rigidity of mounting; or indications of corrosion or rust. • Check for improper functioning of starting and stopping devices. • Check for incorrect fan speed.
Water cooling systems	• Check for evidence of inadequate fluid flow.
Gages and alarms	• Check for dirty, unreadable liquid-level gage and alarm system. • Check for leaks in piping both before opening and after closing tanks of inert gas systems. • Check for inadequate grounding. • Check for improper dielectric strength of insulating liquid. • Check for inadequate insulation resistance.

Table 4-27 describes items that should be checked during inspection of transformers while in the energized state.

Table 4-27
Inspection Criteria for Energized Transformers [1]

Inspection Area	Inspection Criteria
Concrete foundations and supporting pads	• Check for settling and movement, surface cracks, or breaking or crumbling within 2 in. of anchor bolts. • Check for loose or missing anchor bolts, corrosion (particularly at points closest to metal base plates and concrete foundations).
Mounting platform (wooden)	• Check for cracks, breaks, signs of weakening around supporting members; rot, particularly at bolts and other fastenings; holes through which bolts pass; or wood contacting metal. • Check for evidence of burning or charring at wood contact points caused by grounding deficiency. • Check for inadequate wood preservation treatment.
Mounting platform (metallic)	• Check for deep pits from rust, corrosion, or other signs of deterioration likely to weaken the structure.
Hangers, brackets, braces, and connections	• Check for rust; corrosion; bent, distorted, loose, missing, broken, split, or otherwise damaged elements. • Check for evidence of burning or charring at wood contact points caused by grounding deficiency.
Enclosures, cases, and attached appurtenances	• Check for collections of dirt or other debris close to enclosure that may interfere with radiation of heat from transformer or flashover. • Check for dirt, particularly around insulators, bushings, or cable entrance boxes. • Check for leaks of liquid-filled transformers. • Check for deteriorated paint, scaling, rust, and corrosion (particularly at all attached appurtenances such as lifting lugs, bracket connections, and metallic parts in contact with one another).
Nameplates and warning signs	• Check for dirty, chipped, worn, corroded, illegible, or improperly placed signs.
Gaskets	• Check for evidence of leakage, cracks, breaks, or brittleness.
Inert gas systems	• Check for incorrect pressure in system. • Check for leaking gas at pipe and valve connections. • Check for loose gas tank fastenings or loose valves.
Bushings and insulators	• Check for evidence of cracked, chipped, or broken porcelain, indication of carbon deposits, streaks from flashover, dirt, dust, grease, soot, or other foreign material on porcelain parts. • Check for signs of oil or moisture at point of insulator entrance.
Grounding and phase terminals	• Check for overheating evidenced by excessive discoloration of copper. • Check for loose connections bolts. • Check for defective cable insulation. • Check for no mechanical tension during temperature changes.
Instrument transformer junction boxes and conduits	• Check for evidence of loose or severely corroded components, including secondary lead connections.

Table 4-27 (cont.)
Inspection Criteria for Energized Transformers [1]

Inspection Area	Inspection Criteria
Breathers	• Check for holes plugged with debris. • Check for desiccant-type breathers needing servicing or replacement.
Temperature-indicating and alarm systems	• Check for loose fastenings. • Check for rust or severe corrosion. • Check for deteriorated paint. • Check for other mechanical defects and loose electrical connections.
Load ratio control apparatus	• Check for loose connections. • Check for rust or severe corrosion. • Check for lack of lubrication. • Check for signs of burning around conducting and nonconducting parts of terminal boards.
Liquid-level indicators	• Check for rust, corrosion, or lack of protective paint. • Check for cracked or dirty gage glasses such that liquid is not discernable. • Check for plugged gage-glass piping. • Check for liquid level below permissible level indicated by mark for gaging. • Check for signs of leakage around piping, gage cocks, gage glasses, or other indicating devices.
Fans and fan controls for air-cooled transformers	• Check for lack of rigidity in mounting fastening. • Check for dirty motors, evidence of grease, moisture, oil, or overheating. • Check for deterioration of open wiring and conduit that may cause malfunctioning of fans or controls. • Check for improper functioning when manual (not automatic) fan controls are operated.
Water-cooling systems	• Check for leaks in piping, fittings, or valve; visible drainage system plugged; or open ditches for drainage water fouled with vegetation. • Check for evidence of bearing wear, indications of corrosion, external deterioration, and leaks. • Check for incipient deterioration, corrosion, rust, or loose fastenings. • Check for signs of deterioration of temperature devices.
Grounding	• Check for loose, missing, or broken connections. • Check for signs of burning or overheating. • Check for corrosion, rust, or frayed cable strands.

4.4.3.6 Alarm and Public Address

Components in these systems should be visually inspected regularly to ensure that they have not incurred any physical damage or become corroded. Electrical integrity and functionality of each system component should be tested quarterly.

4.4.4 Conveying Systems

Visual inspections and operational checks should be performed on conveying systems to ensure that they are functional and pose no mechanical or electrical hazards. Routine visual inspections and operational checks should be performed in accordance with the guidance provided here.

4.4.4.1 Hydraulic Elevators

Inspection of hydraulic elevators should include the following:

- Check the general appearance of the car.
- Inspect interior controls and indicators for damage/proper operation.
- Note damage to interior panels, ceiling, or floor caused by wear, fatigue, or vandalism. Note excessive corrosion of metal work.
- Check car doors for proper operation; note distortion or binding in operating mechanisms. Check lift cylinder/plunger for smooth and proper operation.
- Check accessible portion of plunger for excessive wear/scoring. Check lift cylinder and immediate piping for leakage.
- Check cylinder hardware for defects (loose or missing fasteners, or corrosion). Check buffer for wear, damage, corrosion, or loose fasteners.
- Inspect floor (exterior) controls and indicators for damage/proper operation.
- Note damage to hoisting doors and frames caused by wear, fatigue, or vandalism. Note excessive corrosion of metal work.
- Check hoisting doors for proper operation. Note distortion or binding in operating mechanisms.

4.4.4.2 Traction Elevators

Inspection of traction elevators should include the following:

- Check the general appearance of the car.
- Inspect interior controls and indicators for damage/proper operation.
- Note damage to interior panels, ceiling, or floor caused by wear, fatigue, or vandalism. Note excessive corrosion of metal work.
- Check car doors for proper operation; note distortion or binding in operating mechanisms. Check lift cables and counterweights for smooth and proper operation.
- Check accessible portion of cables for excessive wear or fraying.
- Check counterweight hardware for defects: loose or missing fasteners; corrosion. Check buffer for wear, damage, corrosion, and loose fasteners.
- Inspect floor (exterior) controls and indicators for damage/proper operation.

- Note damage to hoisting doors and frames caused by wear, fatigue, or vandalism. Note excessive corrosion of metal work.
- Check hoisting doors for proper operation. Note distortion or binding in operating mechanisms.

4.4.4.3 Escalators

Inspection of escalators should include the following:

- Check general escalator appearance.
- Inspect local controls and indicators for damage/proper operation.
- Note damage to side panels or handrails caused by wear, fatigue, or vandalism.
- Note excessive metal work corrosion.
- Check flights for proper operation. Note distortion or binding in operating mechanisms.

4.5 Inspection of External Systems

4.5.1 Walks, Drives, Curbs, and Asphalt Surfaces

Inspection should be made semiannually, preferable in the spring and fall of the year. And just as for any other material, records should be kept detailing the maintenance history of the surface. The inspection procedure should include noting all cracks, holes, depressions, and other types of visible distress.

4.5.2 Runoff, Drainage, and Erosion Control Systems

Visual inspection of drainage and erosion control systems and structures should take place at least once a year. In general, inspections should look for any evidence of water or wind erosion on both surface and subsurface drainage systems. Inspections should also ensure that drainage facilities are kept free of silt bars, snags, vegetation, logs, tree branches, and other debris that encourage silt disposition. Drainage structures made from concrete should be inspected for evidence of cracking, structural integrity, or excessive wear.

4.5.3 Fences

Inspection frequency of fences varies depending on the function of the fence. Fences used for security or personnel barriers should be visually inspected on a monthly basis. Other fences can be inspected on a much less frequent basis, usually annually. Inspection of fences should include checking for any corrosion, physical damage to the fence subcomponents, deterioration of the fence posts, or ripped/torn sections.

4.5.4 Tanks

Inspection of tanks should be performed primarily to ensure that the tank is not leaking its contents into the environment. This is most critical for underground storage tanks, because in many cases, an aboveground or elevated storage tank is provided with a secondary containment structure/pit.

Tank inspections can entail simple visual inspection of the exterior and interior surfaces of the tank walls or more elaborate nondestructive inspection techniques designed to measure the actual thickness and integrity of the tank walls. Inspection of tanks should include checking for excessive corrosion, deterioration of the tank lining, evidence of leaks around piping connections or instrumentation, and evidence of physical damage such as cracks, dents, or bulges.

5
PREVENTIVE AND PREDICTIVE MAINTENANCE

Many of the maintenance activities in this section can be considered both preventive and predictive in nature. Some of the guidance can be categorized as being preventive because the recommended actions are performed on a time- or machine-run-based schedule that detects, precludes, or mitigates degradation of a component or system with the aim of sustaining or extending its useful life through controlling degradation to an acceptable level. Thus, by simply expending the necessary resources to conduct maintenance activities intended by the building element designer, facility life is extended and its reliability is increased.

Some of the guidance can be categorized as being predictive, however, because the recommended actions are measurements that detect the onset of a degradation mechanism. The measurement allows casual stressors to be eliminated or controlled prior to any significant deterioration in the component physical state. These results indicate current and future functional capability. Basically, predictive maintenance differs from preventive maintenance by basing maintenance need on the actual condition of the machine rather than on some preset schedule.

5.1 Routine Maintenance for Major Structural Materials

5.1.1 Reinforced Concrete

5.1.1.1 Prevention of Deterioration

Probably 50% or more of the concrete deterioration in buildings today could have been prevented by effective design and construction techniques. The existing specifications as developed by manufacturers' associations are typically adequate. However, if not followed properly, even by using effective construction techniques, poor concrete—which is susceptible to deterioration—results.

Some of the major ways in which concrete deterioration can be prevented are the following:

- Compact the subgrades properly.
- Provide adequate drainage of the subgrade.
- Eliminate traffic on the compacted subgrade.
- Delay the final finishing as long as the concrete surface remains workable.
- Maintain the controlled rate of concrete placement (as recommended by the ACI).

- Establish and maintain effective inspection and quality control procedures on the job site.
- Begin curing operations immediately after finishing.
- Use adequate vibrating methods (as recommended by the ACI).
- Protect curing concrete from external loads due to impact and ground vibrations.
- Use stiff concrete mixes.
- Use recommended quantities, types of construction, and expansion joints.
- Provide required reinforcing steel.
- Place all reinforcing steel in strict accordance with contract drawings.
- Ensure that all materials in the concrete mixture are at correct temperatures for specific environmental conditions (according to ACI recommendations).
- Use the highest quality materials (as per ACI recommendations).
- Do not use curing compounds on surfaces that are to receive protective treatments.
- Do not use form oils or waxes on forms to be placed against surfaces to be coated.
- Use a minimum cement and water contents in the design mix (do not permit overwetting for workability).

This list can be used as a checklist in the review of existing specifications on concrete construction.

5.1.1.2 Routine Maintenance

The extent and frequency of routine or housekeeping-type maintenance of concrete depends on the exposure, location, desired appearance, extent of any existing deterioration, and available maintenance funds. Columns, walls, and other vertical surfaces that are exposed to the environment are given a minimum of routine maintenance. Regular housekeeping maintains a specified or desired appearance. If appearance is not a problem, the surface could be sealed or left as is and inspected at regular intervals for deterioration.

If, however, vertical surfaces need to be cleaned for the sake of appearance, mechanical means (such as air hoses) or light sandblasting can be used. Chemical etching is also a possibility and should be performed only under safe conditions. Whatever means are used in the cleaning process, do not remove the existing concrete surface, because doing so would decrease the amount of cover on the concrete reinforcement, which—in the long run—would induce further and more dangerous deterioration.

5.1.1.3 Coatings

The durability of concrete can be improved by preventive maintenance in the form of surface treatments. Do not use a surface sealer, which seals moisture into the concrete by preventing evaporation of water penetrating from unsealed surfaces. This is especially true for floors, which receive the most abuse in any building. Coatings can also be placed to add characteristics to the concrete that do not otherwise exist, such as the ability to resist attack from potentially disintegrating types of elements. The magnitude of protection needed in any given exposure depends on the following:

- Temperature
- Concentration of potentially disintegrating chemical agent
- Nature of the potentially disintegrating chemical agent
- Whether the agent is flowing or stationary
- Whether the exposure is continuous or intermittent

Additional guidance on coatings is provided in EPRI report 1003102, *Guideline on Nuclear Safety-Related Coatings, Revision 1 (Formerly TR-109937)* [3].

Coating types. The coatings can be secured to the concrete by bonding, percolation into the pores, or chemical reaction. Coatings give either permanent or temporary protection. In the latter case, the coating surface must be retreated. The ACI has developed a list of substances harmful to concrete along with recommended coatings and/or surface treatments to protect against damage from the respective substance.

Coating application. Proper preparation is the most important aspect of applying coatings to concrete surfaces. General guidelines that should be adhered to in preparation are the following:

- Surfaces should be well cured and free from moisture.
- Objectionable voids in the surfaces should be eliminated. Any voids should be filled with a neat grout.
- All grease, oil, wax, efflorescence, laitance, dust, and loose particles should be removed.

The method used depends on the surface conditions and the type of coating to be used. Acid etching or sandblasting are the methods most commonly used today; however, each manufacturer's recommendations should be followed in order to ensure proper application.

Hardening agents. Effective coatings are available for most degrees of required protection. Coatings are usually categorized in broad areas, and one of these areas contains coatings known as hardening agents. These include such substances as sodium silicate, sodium sulfate, and fluorosilicate hardeners.

Seals and finishes. The other type of general coating classification is referred to as seals and finishes. Soil does not penetrate these coatings. By applying additional coats, protection can be

obtained from excessive wear and thus prolong the life of the concrete surface. Conditions that should be considered when selecting a protective sealant and/or finish are the following:

- The standard of maintenance required
- The amount of traffic (on the floor)
- The type of soil that occurs
- The existing conditions of the concrete surface
- The application requirements
- The degree of maintenance required after applying the finish or sealer

5.1.1.4 Stain Removal

Stains must be removed, not only for the sake of appearance, but also to prevent future material surface damage. The first step in the removal of stains—whether caused by construction activities or through exposure of the concrete during service—is to determine the source of the stain and then select the proper method for removal.

Common mechanical methods for removing some stains are sandblasting, grinding, steam cleaning, brushing, and light blowtorch application. Steel brushes, when used by themselves, wear at times in a manner that leaves iron deposits, which eventually rust and can later stain the concrete.

Chemical cleaning is more involved and requires the application of specific chemicals. The action takes place either by dissolving the staining substance, which can then be blotted from the concrete surface, or by chemically bleaching the discoloring agent into a product having a color that blends with the concrete. Many chemicals can be applied to concrete without appreciable damage to the surface, but strong acids or chemicals having a highly active reaction should be avoided; even weak acids can etch the surface if left on for any length of time. Saturate the surface with water before applying an acid so that the acid is not absorbed too deeply into the concrete. The acid used should be completely flushed from the surface with water.

Some stains can be removed by more than one method. No attempt should be made until one is sure that the method or solvent selected will do the job. Experimentation with different bleaches or solvents is helpful. Some experimentation should be done in an inconspicuous small area of the concrete surface. With careful experimentation, the most effective method and materials can be selected.

With either mechanical or chemical methods, care should be taken to protect surrounding areas and materials other than concrete, such as glass and wood, from the effects of the treatment. Many of the methods described for stain removal refer to a poultice, which is a paste that contains a solvent or reagent and a powdery, inert, absorbent material. The inert material can be diatomaceous earth, calcium chloride lime, or talc. The selection of the solvent depends on the stain to be removed. The paste is usually spread over the stain with a trowel to a thickness of about 1/2 in.

5.1.2 Structural Steel

5.1.2.1 Prevention of Deterioration

The strength of structural steel is controllable when accurate requirements are given. Steel failures are seldom caused by any fault of the material, but mainly by the design and construction of a component or facility. Steel that is inaccessible for periodic inspection and maintenance, such as items buried in masonry construction, must be permanently protected, especially against moisture from outside of the environment or from within the surrounding material. Hidden deterioration that is inaccessible, if allowed to continue, eventually causes deterioration of adjacent materials. Therefore, if specific parts are going to become inaccessible in the future, the most economical decision is to encase them.

Preventive measures against structural steel deterioration that are primarily available during the design stage are the following:

- Make parts of structure accessible to maintenance or encase inaccessible parts.
- Minimize exposure of steel parts.
- Avoid shapes or details that catch dirt.
- Eliminate pockets, low spots, and crevices.
- Protect column bases with concrete encasements.
- Plug or keep open any slots and holes in horizontal surfaces.
- Avoid narrow crevices.
- Draw tight all adjacent metal surfaces.
- Provide full-penetration welds.
- Concrete fill or seal airtight all pipe or tubular columns.
- Isolate dissimilar materials.
- Provide ventilation in spaces around steel members.

Table 5-1 provides actions that can be taken to prevent deterioration or damage of structural steel used in facilities. A brief description of each action is provided.

Table 5-1
Prevention of Deterioration of Structural Steel [1]

Failure Mechanism	Preventive Action
Abrasion	• Replacement of member • Provision of sacrificial metal • Armoring
Corrosion	• Replacement of member • Application of coatings such as painting • Encasement • Replacement with alloys • Provision of sacrificial metal • Cathodic protection • Armoring
Fatigue	• Change loading characteristics • Correct design for this type of failure
Impact	• Elimination or mitigation of consequences of the impact
Lamellar tearing	• Use of appropriate welding techniques
Loosening of connections	• Encasement of connection in concrete • Reinforcement by welding

Painting structural steel. Paint can be used as a protective coating and/or part of a repair process for most types of structural steel, except for the following:

- Areas involving problems of inaccessibility
- Thin sections
- Severe exposure conditions

The important aspects of painting structural steel begin with the correct preparation of the surface. Ensure that the surface is cleaned and free of loose materials, such as grease and rust. Select the correct type of paint or coating based on the application and design basis conditions. After the materials are selected, place the primer on the surface as soon as possible after the cleaning or surface preparation process so that the surface does not become contaminated. Apply the paint with the correct equipment, using qualified painters, and in strict accordance with the manufacturer's recommendations.

Galvanized steel is steel coated with zinc and then treated with chemicals to prevent white rust. A combination of the zinc metal and chemical treatment often creates problems of adhesion of applied coatings after exposure. If the incorrect paint system is used, extreme flaking and peeling away can take place after a year or so of exposure, especially when wide temperature changes take place. Allow galvanized steel to weather, if at all possible, and use primers prior to application of the paint.

The painting process does not end when the coats of paint have been applied. The paint should be inspected after the application of each coat, including the primer, and after the job is completed. During the inspection process, the inspector should check for pinholes, holidays, blisters, and coat thickness.

Periodically, inspect the film thickness of existing paint and repaint the surface when it decreases to 4 mils. Watch for signs of local rusting or corrosion. Spot paint as soon as possible, before general surface preparation and painting are required.

Other protective coatings. These coatings can include bituminous paints, galvanizing, and other coatings, such as those manufactured from plastics. Where longer life protection is required, zinc coating should be considered.

Encasement. Another method of prevention is encasing the member in concrete or another similar material to make it inaccessible to environmental exposure.

Sacrificial metal. The term sacrificial metal denotes an overdesign of the structural element with respect to its thickness requirements. The purpose is to provide an extra amount of material for expected corrosion loss in excess of the structural requirements of the section.

Armoring. Armoring is a means of protecting the structure against damage, especially due to abrasion and impact, by covering or encasing it with another material. Methods of armoring include concrete encasement, wrought-iron plates, timber facings, the provision of sacrificial metal, of hard metals, and the use of abrasion-resistant paint coatings, such as vinyls, neoprene, and baked phenolic finishes.

5.1.2.2 Routine Maintenance

Routine maintenance of structural members consists primarily of inspection and coating repair to ensure that the structural elements are not deteriorating. Repair and replacement of the actual structural members are described in Sections 6 and 7.

The most important aspect of an effective maintenance program for steel is to keep the material clean. Dirt holds moisture, and moisture—in combination with oxygen—causes corrosion. In addition, dirt often hides defects that are occurring or have occurred in a structural member, which can become a very dangerous situation. Therefore, regular cleaning and inspection are probably the most important aspect of day-to-day maintenance of steel members. The cleaning process can take many forms, from basic dusting of the steel that is in a relatively clean environment, to rubbing down with a detergent or cleaning with air under pressure, to controlled sandblasting in an extremely corrosive environment.

5.1.3 Wood/Timber

5.1.3.1 Arresting Decay of Wood/Timber Elements

Because decay (fungi) must have moisture, food, air, and favorable temperature conditions to develop and survive, the elimination of one or more of these prevents this type of deterioration. The deprivations should be permanent.

Moisture. Maintain the moisture content of wood at or below 20%.

Food. Use fungi-resistant woods, or poison the wood by treating it with an appropriate chemical additive.

Air. Cut off the air supply by encasement or embedment.

Temperature. Keep the temperature higher than 110ºF or lower than 35ºF.

The steps that should be taken to treat for and remove any further decay are the following:

1. Remove fungus-infested lumber.
2. Spray infested areas with a wood preservative.
3. Eliminate the causes.
4. Provide ventilation for affected areas.
5. Replace infested lumber with treated lumber.

5.1.3.2 Preventing Termite Damage

Prevention can begin by using good building practices consistent with the geographical region and the type of insect infestation possible. Methods of preventing termite infestation include the following:

- Grade the soil so that it slopes away from the foundation.
- Remove tree stumps, roots, and all untreated wood items from the construction areas.
- Avoid embedding nonpressure-treated wood in concrete.
- Reinforce concrete as necessary.
- Cover hollow concrete masonry with concrete cap block, termite shield, or pressure-treated wood.
- Chemically treat the soil both inside and outside of the foundation wall and prior to the installation of ground slabs.

- Fill joints and cracks with coal tar pitch or acceptable sealer.
- Provide adequate ventilation in crawl spaces.

5.1.3.3 Treatment for Termites

Regular inspection should be made to investigate the possibility of insect damage. When damage is uncovered and repair is needed, the first action should be to destroy the insects by fumigating, poisoning, or removing and destroying all of the material that has been infested. The deteriorated member can be then replaced or reinforced.

Corrective measures include the following:

- Excavate the adjacent grade to remove the timbers away from the soil.
- Drill the infected areas and inject poison.
- Raise the foundation wall or piers.
- Ensure adequate ventilation under crawl spaces.
- Install termite shields.
- Paint with protective coatings.
- Encase the member so that termites cannot get at it.
- Remove the infected wood.

5.1.3.4 Preventive Measures Against Checking

By definition, a *check* is a surface opening caused by seasoning. It does not extend through the thickness of the piece of lumber, but follows the grain of the wood. A *split* (or *through-check*) is a lengthwise separation of the wood extending from one surface through the piece to the opposite surface or to an adjoining surface. The more serious checking or splitting can result at the ends, then through the body of the piece. End-drying (and thus checking) can be minimized by application of paint coatings to the material while it is unseasoned.

If checking occurs when the structural member is in place, two potential hazards exist: 1) possible failure, and 2) a break in the timber surface that can allow insect infestations and decay to begin. Checking that occurs at the end of a member can be controlled by sealing the ends with a commonly available sealer and/or by driving a C-iron into the end. The last method can realistically only be done prior to installation of the timber member. Another effective method that can be used to control checking is the use of bolts. Lumber codes allow for some checking to occur without affecting structural integrity of the member. It is checking beyond this amount about which one must be concerned.

At the ends of members loaded in compression parallel to the grain, checks and splits can be disregarded, provided there is no evidence of slip from wedging action of connectors and bolts. For members loaded in tension parallel to the grain, splits outside the connector area, which are

about parallel to the grain, can also be disregarded. If checks and splits occur in any other locations, give immediate attention to the problem by consulting with the structural engineering organization.

5.1.3.5 Wood Treatments

Decay and insects. Preservative treatments protect wood against decay and insect attack. Research has shown that available preservative treatments extend the life of wood many times. Cost of the initial treatment to prevent wood decay is many times lower than the cost of replacing the member in the future. Therefore, any lumber that will be used: 1) on the exterior of the building, 2) in the interior, in contact with, or in close proximity to the ground, and 3) in below-grade installations, should be treated with a preservative treatment. This information should be specified in the construction documents for the facility or building.

When considering the types of treatment processes, several factors that should be considered are the following:

- Cost
- Structural integrity
- Materials that will be in contact with, or in close proximity to, the treated wood
- Environment
- Effect on the health of humans and wildlife
- Appearance
- Paint adhesion to surface
- Odor

The types of treatment processes are vacuum-pressure impregnation and surface application (nonpressure). The former is more effective and longer lasting, and must be done prior to the installation of the structural member. When the member is in place, the second process is the only process available to preserve the member.

Fire resistance. Fire-retardant chemicals increase the fire resistance of wood. The proper fire-retardant chemical treatment of wood greatly reduces the magnitude of flammable products released. This, in turn, reduces the amount of flame spread over the surface. Treatment also reduces the quantity of heat available or released in the volatile substances during the early stages of a fire. In addition, the timber becomes self-extinguishing when the main source of heat or fire is removed. The treatment does not prevent wood from decomposing under fire conditions. Another beneficial result of this type of treatment is the inhibition of the formation of decay and termite attack. It has been found, however, that fire-retardant treatments can cause early and rapid deterioration of connecting metal hardware and a premature failure of the structure.

5.2 Maintenance of Facility Finish Materials

5.2.1 Exterior Materials

5.2.1.1 Wood Exteriors

Wash exterior wall surfaces with a neutral detergent at least once a year. This cleaning process can take place when the outside windows are washed. After years of exposure, repaint or restain the surface. The American Wood Council recommends painting, not staining, for all exterior plywood surfaces. Otherwise, it deteriorates in less than a decade.

5.2.1.2 Metal Exteriors

Where severe wind or vibration affects the stability of the siding, apply additional bracing and fasteners according to the siding manufacturer's recommendations. Preventive measures include the following:

- Keep all bolts, clips, rivets, nails, and other ties and fasteners tight. Where corrosion or rust has destroyed the effectiveness of a fastener, replace it immediately. Where stresses have damaged the siding connection with a fastener, patch as necessary with matching material and replace the connector to ensure a positive connection. Use stainless steel or aluminum nails and neoprene washers for trouble-free service, because they not only waterproof the joint, but prevent corrosion. It is often advantageous from the standpoint of maintenance to use double-headed nails in placing corrugated metal siding.
- Where sections of metal siding have been bent or cut, remove and straighten the section making neat patches where necessary. If damage is severe, replace the panel with a matching substitute. To prevent vehicles (for example, forklifts) from striking and damaging the siding, provide the building with bumper guards.
- If metal buildings have interior insulation, take care to not damage existing construction and utilities when repairing or replacing metal wall coverings.
- Keep ventilators in metal buildings clean and clear of obstruction. Keep door-sliding devices and locks in adjustment and tightly fastened.
- Wash and coat at specific frequencies depending on the environment. Wash using a solution that contains a detergent specifically prescribed for the type of metal.

Protected metal sidings. Protected metal sidings are designed to give reasonably long service, but damage from abrasion can expose the metal core to corrosion or reduce the thickness of the protective coating. Unless the damaged areas are repaired, touched up, or recoated as necessary, serious damage can result. If structural changes to a building make it necessary to cut existing protected metal surfaces, treat the affected areas to prevent corrosion.

Cleaning. Before repairing, touching up, or recoating a metal exterior surface, clean the affected area. Remove all loose or torn felt, flaked coating, and rust with a stiff fiber brush. Remove dust, chemical deposits, grease, and dirt. Use synthetic detergent cleaner to remove chemical deposits and grease. Scrape off thick deposits of grease with a trowel or putty knife before using the detergent cleaner. Remove rust with a wire brush. The coatings on protected metal are usually petroleum asphalt compounds that can be softened or dissolved by organic cleaners and solvents. Do not use naphtha, bensol, sylol, or carbon tetrachloride for cleaning protected metal surfaces.

5.2.1.3 Masonry and Concrete Exteriors

Routine maintenance procedures for masonry include the following:

- Wash (at regular intervals): washing can be accomplished by chemical and steam cleaning, hand washing, high-pressure cold-water blasting, high-pressure steam, and sandblasting.
- Paint (at infrequent intervals).
- Replace sealants in control joints.

Other maintenance activities, which are performed less frequently, include the following:

- Stain removal (similar to stain-removal techniques provided for reinforced concrete surfaces).
- Caulking.
- Removal of efflorescence: efflorescence can be removed by vigorous and repeated scrubbing with a stiff fiber or wire brush and clean water. If this does not work, scrub the surface with a solution of hydrochloric (muriatic) acid having a concentration not stronger than one part acid to nine parts water by volume.

  Before applying the acid solution, dampen the wall surface with clean water. Apply acid solution to small areas of about 4 to 5 ft^2 at a time. Let stand 5 minutes and follow with a scouring of the treated surface with a stiff bristle brush. Immediately follow with a rinsing of the wall with clean water. Protect all windows and trim from destruction by the acid.

5.2.1.4 Mineral-Surfaced Board Exteriors

These materials require little maintenance except to keep fasteners secure and to remove stains from other sources. Painting should be performed in accordance with each manufacturer's recommendations.

Prevention of deterioration. Mineral-surfaced siding is a high-grade finish material that should be properly and carefully handled during transportation and application. Take extreme care to keep the product dry and to not apply the siding over wet sheathing or underlayment.

Cleaning and stain removal. Thoroughly dry brush the areas to be cleaned to remove the dust and loose material, and then scrub with a floor-scrubbing brush, using a cleaning compound appropriate for the type of stain encountered. Immediately following the application of the cleaning compound, thoroughly rinse the entire area treated with clean water. The most common types of stains occurring with these products are the following:

- **Window screen stains.** To remove stain, use a dilute solution (5%) of white vinegar.
- **Copper stains.** Use a paste consisting of 1 part ammonium hydroxide, 10 parts water, 16 parts talc, and 4 parts ammonium chloride, then add the liquid in sufficient quantity to form a heavy paste. Carefully apply the paste with a trowel or scrubbing finish over the entire surface. After 24 hours, thoroughly wash the dried paste from the stained surface.
- **Earth stains at grade line.** Dry brushing and rinsing usually removes ordinary earth stains.
- **Rust stains from nails, hinges, gutters, and leaders.** Iron rust stains can be cleaned with a 2% solution of oxalic acid or a 5% solution of phosphoric acid. Wash the surface with the solution, and follow with a thorough rinsing with clean water.
- **Stains from unpainted wood trim.** Stains caused by water running over unpainted wood trim can often removed by scrubbing them with common cleansers. If the stains are deep, scrubbing with a strong solution of sodium hypochloride or a 2% solution of oxalic acid might be necessary.
- **Dirt and soot stains.** These stains can often be removed with a mild cleanser such as ordinary soap or a weak solution of trisodium phosphate or other commercial detergent. Use a stiff wire brush.
- **Discoloration from oil-stained wood shingles.** In cases where surfaces are discolored from oil-stained wood shingles, it is generally necessary to use a two-part solution treatment. First apply a 20% solution of sodium citrate, brushed on and allowed to dry. Then apply a 20% solution of phosphoric acid with a scrubbing brush. This coat readily removes the stains, but in some cases it can leave a slight “bloom.” Where this happens, it is necessary to wash the entire area with a dilute (5%) solution of phosphoric acid. It is most important with this method to thoroughly scrub the wall surface as well as concrete foundation, sidewalk, and so on, with clean water to remove all traces of acid and bloom.
- **Paint stains.** Wipe off stains with a cloth soaked in turpentine or other paint solvent. If the paint is old and dried, repeated application might be necessary, after scraping with a knife blade.
- **Oil and grease stains.** Use a paste consisting of 3 1/2 lb of whiting mixed with 1 qt of cleaning solvent, benzene, or naphtha. Apply with a trowel and follow by wiping with a clean, dry cloth.

5.2.2 Interior Ceiling and Wall Materials

5.2.2.1 Plaster

The most frequent maintenance problems with plastered and gypsum board surfaces are cracks, holes, loose segments, and water stains. To effectively maintain plaster surfaces, ensure that they have been sealed with an acceptable high-quality sealer or commercially available paint. Routine maintenance procedures can include dusting and/or washing.

Dusting. Use a dust mop or vacuum cleaner, clean cloths, and a dusting compound. The process is usually started at the ceiling and is followed by dusting the walls from the top to the floor.

Washing. Periodic washing indicates good housekeeping. Do not use abrasive or caustic cleaners, because they can scratch the surface. If anything stronger than mild soap is required to remove dust, then the housekeeping frequency is incorrect, and the wall surface treatment is inadequate. In cases where the ceiling requires cleaning, wash the ceiling prior to washing the walls.

5.2.2.2 Drywall

Drywall needs periodic maintenance similar to that of plaster. In addition, secure all nails, screws, and other fasteners, if needed.

5.2.2.3 Ceramic Tile

Cleaning of ceramic tiles should be done in accordance with the tile manufacturer's recommendations to avoid damage to the glazed surfaces. Depending on the location of the tile, daily dusting might be needed, following the same procedure described for dusting walls. Periodically, wash ceramic tile with a noncaustic, nonabrasive agent. Take care to not harm the mortar in which the tile is set. A sealant can be applied to the wall to prevent future deterioration of the mortar. An abrasive cleaner, such as scouring powder, can be used with a small, stiff brush to clean out the joints.

5.2.2.4 Acoustical Tile

The basic maintenance program for acoustical tiles should be similar to that for gypsum board. Remove loose dirt and dust with a soft brush, cloth, or vacuum cleaner. In most cases, spots and streaks can be removed using an art gum eraser. Wallpaper cleaner can be used for larger marks. Acoustical tile can be washed with a mild detergent using reasonable care. Commonly available cleaners especially designed for acoustical tile can be obtained commercially or from the original manufacturer.

5.2.2.5 Wood

Wood used for walls or ceilings is usually obtained in the form of panels, such as 4- x 8-ft sheets of paneling. At regular intervals, dust wood walls and ceilings with a soft cloth or vacuum cleaner. If the wall and ceiling material is not prefinished, apply a sealant coat that is absorbed into the pores of the wood. Avoid using water on finished or unfinished wood. Use only the wood cleaners recommended by the manufacturer. Periodic waxing with a high-quality wax or oil helps to preserve the wood.

5.2.3 Floors

5.2.3.1 General Guidance

The daily maintenance of floors should be protective of and preventive to damage of the finishing materials. For this reason, floor maintenance requires much consideration and effort, more than for any other type of interior material. The factors that should be considered when establishing a floor maintenance program are the following:

- Frequency of cleaning (such as brushing, sweeping, and washing)
- The pH and concentration of the cleaning solutions
- Weight of fixed and moving objects
- Amount and frequency of traffic (abrasion on floor)
- Quantity of airborne dust settling out on floor
- Grinding in of settled dust
- Formation of oily films
- Oxidizing effects of atmosphere
- Exposure to color-fading light rays
- Attack by industrial gases and chemicals (possible stain producers)
- Extreme changes in temperature and humidity
- Attack by fungi, insects, and animals

Take care to select the appropriate detergents, waxes, sealers, and equipment for maintaining floors, with close attention to each particular manufacturer’s recommendations.

5.2.3.2 Types of Routine Floor Maintenance

Manual sweeping and dust mopping. This process simply uses a broom and a dustpan.

Manual floor mopping. This process can include damp mopping, wet mopping, or scrubbing. Damp mopping or buffing is usually done between waxings. Wet mopping removes greater quantities of dirt and is used when the floor requires a rinsing with clean water. Scrubbing uses an electric cleaning machine.

Stripping. Stripping removes dirt and wax buildup on a floor, typically using a power floor-cleaning machine and an appropriate stripping compound or detergent.

Waxing and buffing. Waxing and buffing achieves a hard luster and finish to the floor using an appropriate floor wax and an electric buffing machine.

Power sweeping. This process uses an electric vacuum to remove large quantities of loose dirt from floors and carpets.

Carpet mopping. This process uses a wet mop and an appropriate mopping solution on a carpet to manually wash the surface of the carpet.

Shampooing. Shampooing uses a power scrubber, brushes, vacuum cleaner, and an appropriate rug and carpet shampoo solution to deep clean the fibers of the floor covering.

5.2.3.3 Detailed Floor Maintenance Procedures

Resilient flooring. These floors must be cleaned and then protected from their exposure conditions. After the floor is cleaned, it is finished to fill the irregularities and seal the pores. This results in easier future cleaning, improves the appearance, and prevents further damage from abrasive dirt. The protective finish itself is affected by the same abrasive dirt; therefore, the type of protective finish that is placed on the floor surface should be easily removable. A good grade of wax should be applied in thin coats to the surface.

Always use a cleaning detergent or product specifically designed and recommended for the type of resilient floor being maintained. The facility often has more than one type of resilient floor. Avoid the excessive use of water or cleaning solutions. Do not use abrasive agents on the floor surface, and avoid harsh alkaline solutions.

- **Asphalt tile.** Use a soft-bristle broom or a dust mop to clean the floor. If a sweeping compound is to be used, ensure that it is water based rather than oil based. Apply a mild, neutral chemical cleaner and allow it to penetrate the tile. Do not use an alkaline cleaner with a pH greater than 11. Do not use scouring powder and solvent-type cleaners. Sealing is mandatory for asphalt tile, using the product(s) recommended by the manufacturer. Follow the sealing with the application of a water-based emulsion wax or resin floor polish. Buff the dry floor after the application of two thin coats of the polish.

- **Cork tile.** Natural cork tile must be sanded, sealed with an alcoholic shellac or other sealer, given several coatings of a solvent-based paste or liquid wax, and buffed. This might be required every 12 to 18 months if a heavy traffic condition exists. The floor can be damp mopped if needed; but if possible, use a neutral cleaner rather than water. If the tiles are badly soiled, use a steel wool pad with the cleaning solution. Factory-waxed cork tile is impregnated with a wax composition at the factory and does not require a finishing treatment at the time of installation. Resin-reinforced cork tile is saturated with a resin at the factory. It is somewhat less porous and therefore smoother than the other varieties of cork tile.
- **Linoleum tile.** Abrasives should not be used except at isolated times. Nonalkali cleaners should be used. Use either solvent-type water wax or emulsified resin finishes on linoleum tile.
- **Rubber tile.** For stubborn accumulations, a mild abrasive cleaner or steel wool with a synthetic detergent can be used. Steel wool pads and a good wax stripper are effective in removing old wax coatings. Use only a water emulsion-type wax because other types of waxes soften the tile.
- **Vinyl composition floors.** Dust mop or sweep these floors on a daily basis. Damp mopping can be performed as needed, and buffing should be done using a nylon or steel wool pad. Do not use abrasive cleaners on unwaxed floors. This type of floor should be sealed and should be resealed at every sixth waxing thereafter.
- **Vinyl plastic tile.** Depending on the wear of the tile, it might not need to be sealed. If it is poorly maintained, pitted, and is rough surfaced, some type of rejuvenation, such as sealing, may be appropriate. Otherwise, it is not needed due to the denseness of its composition.

Masonry floors. The same basic periodic housekeeping operations should be used on this type of floor as those described for resilient flooring.

- **Ceramic tile.** Sweep ceramic tile floors daily with a wax dressing. Clean the floors with a nonalkali synthetic detergent. Do not use a soap-based detergent because it tends to build up film that catches dust and causes slipperiness of the surface. Wax the floor only when needed, using a water-emulsion wax. Do not use grit or abrasive powder cleaner because they can cause scratching. Do not use steel wool because rust stains could result.
- **Concrete.** Two coats of sealant are recommended to produce maximum wear resistance and a smooth, easily maintained surface. The type of seal depends on the exposure condition of the floor. Vacuum or sweep the floor on a daily basis.
- **Magnesite.** This type of flooring should be sealed with a penetrating, alkali-resistant floor sealer. Vacuum or sweep the floor on a daily basis, and use mop sprays and sweeping compounds. Periodically, scrub the floor using a mild, neutral synthetic cleaner. Use degreasers to remove grease and hardened soil. Do not use trisodium phosphate, silicate soda ash, or any type of acid cleaner. After washing the surface, seal the surface with a solvent-type or water wax. After the wax has dried, buff the floor.
- **Terrazzo.** The surface should be treated with a penetrating-type sealer for reasons of protection, attractiveness, safety, and ease of maintenance. This will also help prevent dusting and staining. The sealer is mainly to protect the grout material. Periodically, reseal the floor to

eliminate the need for waxing. Vacuum or sweep the floor on a daily basis. To wash the floor, use a neutral liquid cleaner that has a pH of 10 or less. Do not use soaps and scrubbing powder containing water-soluble organic salt. Do not use steel wool on the floor. Buffing restores the luster to the surface after it is washed. Do not expose the floor to acid, alkalis, or oils. Wax is not needed, but it enhances the beauty of the terrazzo.

- **Slate tile.** The maintenance and repair procedures used for slate tile should be the same as those used for ceramic tile.
- **Brick flooring.** The maintenance and repair procedures used for brick flooring should be the same as those used for ceramic and slate tiles.

Metal floors. Sweep metal floors on a daily basis. For more stubborn dirt, scrub the floor with an electric floor machine. Steam cleaning is also effective in cleaning the floor. Sanding and sandblasting are two techniques that can be used to clean deeply set-in dirt and stains. It is not advisable or beneficial to wax metal flooring or to use sealers.

Seamless floors. Dust mop seamless floors on a daily basis and damp mop when needed. For more stubborn dirt, use a mop or machine and a neutral detergent to scrub the floor. Do not use nylon abrasive pads, steel wool, or scouring powder. Buffing brings out the highlights of the floor. From the standpoint of wear, sealing and waxing are not needed for this type of floor. However, a thin coat of wax enhances the beauty of the floor, and makes for a somewhat easier removal of spills and stains. Do not use nitric acid and/or acetic acid around the floor. Do not allow grease, oil, or water to stand on the floor for any length of time.

Wood floors. Sweep wood floors daily with an untreated dry mop or bristle brush. Do not use an oil-based sweeping compound. Periodically, dry buff the surface using a fine steel wool pad on a rotary-type electric buffing machine. Remove marks and discoloration with a finish-type cleaner. Periodically, strip and rewax the floor. Never apply soaps, strong detergents, or emulsion-type waxes. It is not a good idea to apply wax to an unsealed wood floor surface.

Carpets. There are four major methods of cleaning carpets for the removal of stubborn dirt: dry-foam or granular cleaning, wet shampooing, steam cleaning, and in-plant cleaning. A regular routine maintenance program should include daily vacuuming in high-traffic areas, twice weekly in medium-traffic areas, and at least once a week in light-traffic areas. Spot clean and destain as needed. Absorbent powder cleaners can be used between wet cleanings to prolong the period between wet cleaning and to enhance the beauty of the rug. When using the wet type of cleaner, use a neutral detergent in accordance with the manufacturer's recommendations. Do not use soap, ammonia, washing soda, or any of the strong household cleaning agents intended for use on hard surfaces such as linoleum or tile.

5.2.4 Roofs

5.2.4.1 Built-Up Roofs

Clean off loose dirt or dust by sweeping, vacuuming, or air blasting. One coat of asphalt primer can be applied by brushing, avoiding excess primer. After the primer is dry, apply an asphalt emulsion at a rate of 2 gallons per square. Immediately after applying the emulsion, while it is still wet, embed strips of fibrous glass mesh in the emulsion, lapping the strips 2 in., and use a moistened brush to force the mesh into the emulsion. Use clay-type emulsion with a glass membrane. Over the fibrous glass strips, while the first coat of emulsion is still wet, apply a second coat of emulsion at a rate of 1 gallon per square. Brush the second coat into the mesh with a fiber brush. Allow the second coat of emulsion to set firmly at least 12 hours in good drying weather, longer in damp, humid weather. Apply a final coat of emulsion at a rate of 2 gallons per square.

5.2.4.2 Asphalt Shingle Roofs

Asphalt shingle roofs that are properly applied usually require no special maintenance or repair treatments. Shingles normally last for years with little change in appearance. The first indication of normal weathering is the loss of mineral-surfaced granules, slight at first, but accelerating as the loss of granules exposes more of the asphalt coating to the weather. No definite periods can be ascribed to the various phases of weathering because they vary with the direction of exposure, the climate, and the slope of the roof. Weathering is more rapid in hot, humid climates, on southern and western exposures, and on low-pitched roofs.

5.2.4.3 Asphalt Rolled Roofs

Smooth-surfaced. Smooth-surfaced asphalt rolled roofing, normally used on temporary structures (and recommended only on roofs of a certain pitch), should receive only the minimum amount of maintenance or repair to keep it leakproof. The first effect of normal weathering on smooth-surfaced rolled roofing is the loss of the fine mineral matter used to prevent sticking of the rolls. The asphalt coating, being exposed directly to the weather, deteriorates more rapidly than mineral, or mineral-surfaced roofing. Recoating is usually required within three to five years. Recoating is required earliest in hot, humid areas and on buildings—such as kitchens and washrooms—where excessive moisture conditions prevail.

Mineral-surfaced. Weathering of mineral-surfaced rolled roofing is similar to that of asphalt shingles, that is, normal weathering proceeds slowly and is first evidenced by the loss of granular surfacing. Recoating of mineral-surfaced rolled roofing is not generally recommended, although it can be used to extend the life of a roof if re-roofing does not appear to be justified.

5.2.4.4 Asphalt Cement Roofs

A rigid frame is required for this type of roofing because of its tendency to crack at the fasteners when small movements occur. A double overlap of the joints and careful sealing during installation are required to reduce moisture penetration during windblown rains. Roofs should have a pitch of not less than 4 in. per ft.

When only a few shingles or corrugated sheets are broken, they should be removed and new ones applied. When a large percentage (25% or more) is broken, they should all be removed and a new roof applied. The present condition of undamaged units should determine whether those salvaged from the old roof should be reused with the new ones.

When an asphalt cement roof fails because of the deterioration of the fasteners, the failure is usually a general one and piecemeal repair is futile. When such failure occurs, usually on a very old roof, it is best to remove the entire roof. Its age and condition should determine whether the old roofing should be reapplied. Normally, if the roofing can be removed without damage, it can be reapplied safely.

5.2.4.5 Metal Roofs

Copper roofing. Copper is one of the least chemically active metals used for roofing. Consequently, copper roofing of adequate weight and applied properly renders long service. When copper roofing is exposed to the atmosphere, a green coating forms on the exposed surface. This coating aids in protecting the metal from further corrosion. The most common cause of failure in copper roofs is the failure to adequately provide for expansion and contraction, particularly in flat-seamed roofing. Broken soldered seams and banks in the metal at points other than seams indicate inadequate provision for expansion and contraction. Copper roofs do not normally require maintenance. Any repair needed, following failure, should be done immediately.

Tin roofing. Tin roofs should be maintained by periodic painting. The frequency of painting varies with different conditions of exposure, but painting should never be deferred until rust appears nor should thick coatings of paints be built up by too frequent painting.

Galvanized-steel roofing. Galvanized-steel roofs need not be painted immediately following exposure. In fact, without special treatment or the use of special paints, it is better to postpone the painting of galvanized steel for at least several months to ensure adhesion of the paint. Painting can be postponed until the appearance of a bright yellow corrosion product that indicates that the zinc coating is no longer serving its protecting function.

Aluminum roofing. Aluminum roofing, if properly applied, does not normally require maintenance. However, if evidence of severe atmospheric corrosion occurs, the roofing can be preserved by regular maintenance painting. Failures in aluminum roofing that result from improper application are essentially the same as with galvanized-steel roofing and are similarly repaired.

Protected-metal roofing. Protected-metal roofing takes its name from the fact that it consists of steel-based sheet that is protected from the weather by a factory-applied coating. Because these are such special items, the recommendations of the manufacturer should be followed with regard to maintenance and repair. With materials of this kind, it is practically impossible to avoid some breaks in the protective covering during application. To cover such breaks and to renew the protective coating when exposure makes a renewal necessary, use only materials furnished by the manufacturer to ensure that the new material is compatible with the old.

5.2.4.6 Slate Roofs

If only a few pieces of slate are broken, they should be removed and new ones applied. If a large percentage (25% or more) is broken, they should all be removed and a new roof applied. The age and condition of the undamaged slates should be determined to decide whether they can be reused. No definite criteria can be given to determine whether a slate should be reused. However, if the part that has been exposed is not faded appreciably, shows no evidence of disintegration, and if the slate gives a sound ring when it is held as lightly as possible between the thumb and forefinger by one corner and struck a sharp blow with the knuckles, it can be used safely.

When the failure of a slate roof results from failure of the fasteners, the failure is usually a general one. As with asphalt cement roofing, piecemeal repair is futile, and it is preferable to remove the whole roof. Whether the old slate should be reapplied must be determined by its age and condition.

5.2.4.7 Wood Shingle Roofs

Warped shingles do not usually cause leaks and, except for appearance, are not immediately objectionable or in need of routine maintenance. Warped shingles are likely to crack eventually, at which time they should be removed. Warped shingles should never be face-nailed except in preparation for reroofing, because the nailing is likely to crack the shingles and the nails work loose, permitting the roof to leak.

Broken wood shingles can be removed by the methods similar to those for removing slate, but at least four nails must be cut. After the broken shingle is removed, a new one of the same size should be inserted and nailed through the exposed butt, preferably with thin copper nails. The shingle immediately above should also be nailed through the exposed butt.

5.2.4.8 Single Membrane Roofs

Because there are many varieties and manufacturers of this type of roofing, the user should consult the manufacturer regarding any recommended maintenance practices for these types of roofs. The Single-Ply Roofing Institute is another source that can provide maintenance guidance.

5.2.5 Windows and Doors

5.2.5.1 Windows

Window washing. The frequency of window washing depends on the environment. Prepare the window washing solution in accordance with the manufacturer's recommendations, or use a commercially available agent. Take care to ensure that all frames and surrounding areas are wiped clean and that no excessive cleaning agent is left on these surfaces.

Wood windows. Activities that can be conducted as part of normal routine maintenance for wood windows are the following:

- Alleviate the effects of weathering by protecting surfaces of frames and moldings with paint or similar coatings.
- Unbind windows by slightly expanding the window frame, removing any foreign matter or built-up paint, waxing the sliding components, and planing the window rails.
- Renail window components to restore the shape of frames that have been forced out of shape by settling, shrinkage, or twisting.
- Cut or plane a sash or frame to address swelled components.
- Replace or repair broken or missing cords.
- Adjust the balance following the manufacturer's recommendations.
- Replace any broken or cracked window panes.

Metal windows. Maintenance of metal windows is usually considerably less involved than that for wood windows. It is important to lubricate the mechanisms regularly and to keep fastening devices secure. Problems of alignment caused by building settlement should be adjusted in conjunction with overall corrective measures, which can involve stabilizing the foundation and frame. Maintain caulking in good order to prevent leakage of moisture and air.

5.2.5.2 Doors

General. Periodically, dust the doors, the frequency depending on the environmental exposure conditions. At least twice a year, wash the door and frames using a mild detergent compatible with the material of the door.

Butt-hinged wood doors. Activities that can be conducted as part of normal routine maintenance for butt-hinged wood doors are the following:

- Alleviate the effects of weathering by protecting surfaces of frames and moldings with paint or similar coatings.
- Unbind doors by slightly expanding the door frame, removing any foreign matter or built-up paint.

- Install a filler (cardboard or metal shim) at the outer edge of the jamb and hinge mortise to address shrinkage of the door.
- Install diagonal batten braces from the top of the lock side to the bottom of the hinge side to address a sagging door.

Panel wood doors. Activities that can be conducted as part of normal routine maintenance for panel wood doors are the following:

- Remove and refit the head stop while the door is closed in order to stop rattling of the door.
- Adjust the fit of hinges.
- Place an additional hinge midway between the other two to address a door that is warped and difficult to close without considerable pressure exerted against the bulging part.
- Plane the surface at either the top or bottom rail for proper clearance, or refit the doorjamb to address either settling of the frame or shrinkage of the door.
- Trim the door to achieve the necessary fit and seal.
- Replace weather stripping, caulking, and trim.

Metal doors. Because the majority of metal doors and fittings are shop designed and fabricated, it should be assumed that they maintain their shape and mechanical operating ability provided hinges, locks, and other fittings remain secure. Frames should remain plumb and corners squared so the door fits its openings with proper clearances. Maintain weatherproofing and caulking and replace if they become dry and lose their sealing capability or flexibility.

Storm doors. Storm doors are commonly made of wood or aluminum with appropriate glazing. Wood storm doors should be maintained according to the guidance provided for wood doors. Aluminum storm doors require little maintenance. Periodically, clean the guide tracks and sash. To keep them operating smoothly, provide a spring-loaded safety chain. For both wood and aluminum screen doors, use a door closer to keep the door closed when not in use, plus a latch to keep the door in a closed position.

Screen doors. Screen doors made with wood or aluminum frames should be fitted with wire guards and wood or metal push bars on the interior side to avoid pressure on the screening. Maintain wood screen doors as recommended for wood doors.

5.2.6 Coatings for Exterior Surfaces

The principal objective of painting is to prevent deterioration of the material at a minimum cost per square foot per year. The real economic concern is the cost per square foot divided by the years served between repainting. One procedure frequently used for providing protection has been to completely repaint after the original has failed. This failure results in an unsightly surface, expensive preparation before repainting, and possible deterioration of structural members. Another procedure is to completely repaint by applying two or even three coats at arbitrary intervals. This might be too late in cases where deterioration has already taken place, and

unnecessary in others. Extensive surface preparation is required in the former case, and film thickness eventually becomes excessive in the latter case, leading to early failure by cracking and peeling. The most practical method of protection is a continuous program of inspection and painting as necessary.

Some suggested frequencies for exterior painting are the following:

- White paint: once every four years
- Lightly tinted paints: once every four to five years
- Deeply tinted paints: once every five to six years
- Dark colors: once every five to eight years

In environments that are more destructive to the coatings, these frequencies might need to be decreased. Therefore, another general rule would be to repaint at either the first sign of chalking on the south side of a structure or general checking (50% or more of the area).

5.3 Routine Maintenance of Facility Systems

5.3.1 Water Distribution Systems

5.3.1.1 Fresh and Waste Water Plumbing Systems

Routine maintenance of plumbing systems typically involves regular inspection of the systems and their components as described in Section 4, and also minor repair of inoperable system components. In some cases, system repair can require the replacement of a given component in lieu of trying to repair the inoperable component. Maintenance practices can also include tests such as flow tests, pressure tests, and leak tests. The frequency of these tests varies depending on the type of system, the age of the system, and the manufacturer's recommendations; but in general, they should be performed annually.

Table 5-2 describes recommended routine maintenance activities for valves installed in plumbing systems.

Table 5-2
Recommended Routine Maintenance for Valves [1]

Component	Suggested Maintenance	Frequency
Gate valve	Check operation.	Semiannually
	Lubricate stem packing.	Semiannually
	Tighten packing gland or replace packing.	Semiannually
	Replace broken or stripped stem.	As needed
	Replace or resurface leaking valve seats.	Annually
	Lubricate chain wheels.	Quarterly
Butterfly valve	Adjust stem for water tightness.	Semiannually
	Operate valve and adjust to achieve required seal.	Semiannually
	Replace seals.	Annually
Rotary valve	Lubricate metal-to-metal contacts in pilot mechanism.	Quarterly
	Lubricate packing glands.	Quarterly
	Lubricate all parts of seating and rotating mechanisms.	Quarterly
	Lubricate gearing.	Quarterly
Globe valve	Adjust packing nut and replace packing if necessary.	Semiannually
	Remove valve stem and disk, grind seat/disk.	As needed
Diaphragm valve	Lubricate valve stem as necessary.	Semiannually
	Replace cracked diaphragms.	As needed
Sluice gate	Lubricate stem screws and gears.	Quarterly
	Clean valve with wire brush and paint as needed.	Annually
	Adjust seating wedge.	Annually
Check valve	Clean and adjust the closure control mechanism.	Annually
	Replace worn pins.	As needed
	Adjust seating.	As needed
Float valve	Repair float.	As needed
	Repair or replace valve operating mechanisms.	Annually
Valve accessories:		
gear boxes	Lubricate gears.	6 months
	Clean housings of corrosion and paint as necessary.	Annually
valve boxes	Clean debris out of box, remove corrosion.	6 months
	Realign rotating elements and adjust as necessary.	6 months
valve stands	Lubricate stem and indicator collars.	3 months
	Clean and paint as needed.	Annually

Table 5-3 describes recommended routine maintenance activities for pumps installed in plumbing systems.

Table 5-3
Recommended Routine Maintenance for Pumps [1]

Component	Suggested Maintenance	Frequency
Centrifugal pumps (horizontal and vertical)	Check hand-oiler, adjust accordingly. Check solenoid-oiler leads, oil flow, adjust accordingly. Check and fill ball-bearings oil level. Refill oil cup for enclosed-shaft-type bearings. Add fresh grease to ball-thrust bearings. Check grease cup of grease-sealed packing gland. Add grease to guide bearings. Drain, flush, and replace lubricant in shaft bearings. Clean and replace grease in bearing housings. Lubricate universal joint couplings.	Daily Daily Daily Weekly Monthly Daily Monthly Quarterly Quarterly Semiannually
Antifriction bearings	Check temperature and adjust lubrication. Drain lubricant, wash housings, replace lubricant. Replace bearing.	Monthly Quarterly Annually
Sleeve bearings	Check temperature and adjust lubrication. Drain lubricant, wash housings, replace lubricant. Check and replace oil rings. Replace bearing.	Monthly Quarterly Quarterly Annually
Stuffing box packing	Check for free movement of gland, oil the gland and bolts, check for excessive leakage, repack if needed.	Semiannually
Gland assembly packing	Tighten gland if leakage is excessive, inspect sleeve, repack if needed.	Weekly
Shafts	Repair or replace shaft.	As needed
Wearing or sealing rings	Replace if clearance is greater than 0.05 in. on a diameter of the ring.	Annually
Impeller	Weld cavitation pits; machine and rebalance. Replace impeller.	As needed As needed
Casing	Clean and paint.	Annually

5.3.1.2 Fire Protection Systems

Guidance regarding routine maintenance of fire protection system components is provided in EPRI report 1006756, *Fire Protection Equipment and Surveillance Optimization and Maintenance Guide* [4].

5.3.2 Heating, Ventilating, and Air Conditioning Systems

The information in this section should be used in conjunction with the requirements suggested by the manufacturer of each system component. In all cases, the manufacturer's maintenance recommendations should take precedence over the general guidance provided here.

5.3.2.1 Duct and Air Transport Systems

In addition to the routine inspections described in Section 4, duct system maintenance can include replacement of seals, tightening of connections/flange members, and replacing/repairing torn fabric.

Fans and blowers. For fans and blowers having adjustable sheaves, adjustment should be made in accordance with the manufacturer's instructions. Lubrication of bearings and rotating elements may also be part of the manufacturer's recommended maintenance instructions.

Dampers and louvers. Usually, cleaning and lubricating with grease are all that are required to maintain gravity dampers. Maintenance for automatic dampers is usually performed when air conditioning and heating equipment is checked. Clean the damper and lubricate it with grease, and check the motor and thermostatic control device for proper operation. Clean the louver screens on a regular basis. Replace damaged parts and paint louvers when necessary.

Expansion and construction joints. No specific maintenance is required for expansion joints and bends other than inspection for alignment. Repair or replace defective parts as required. Lubricate slip joints every six months or in accordance with the manufacturer's recommendations. Usually no lubrication is required with flexible ball joints, because there is little friction or wear. The frequency of gasket replacement depends on operating conditions; replace gaskets as required in accordance with the manufacturer's instructions.

Anchors. If the anchor has shifted, the line should be taken out of service and the anchor secured in place as required. Make necessary adjustments or repairs to the expansion joints and guides.

Hangers and supports. Defective parts should be repaired or replaced as required. Line sags caused be misalignment can often be corrected by simple hanger adjustment.

Traps, drains, and vents. After the yearly inspection, defective gaskets, bellows, valves, valve seats, floats, buckets, linkages, and orifices should be repaired or replaced as required in accordance with the manufacturer's instructions. Repair or replace leaking bypass valves and repack valve stems.

Air vents. At least once a year, air vents should be inspected and cleaned. Use air pressure to blow the vent. If vent performance cannot be corrected by cleaning, replace it. Dirt on the valve, failure of the thermostatic element, or a water pocket in the vent connection can result in water and steam spouting in the vent.

5.3.2.2 Heating Systems

Forced warm-air systems. The typical primary maintenance problem is balancing the system for continuous air circulation, which should be done at the time the forced warm-air heating system is installed. If the system becomes out of balance, either in-house personnel—using manufacturer's

instructions—or an outside heating and air conditioning contractor should rebalance the system. The main items to check when balancing the system are the following:

- The two thermostats (one in the heated room and one in the warm air supply plenum)
- The capacity of the heat source
- The adjustment of the registers
- The speed of the blower motor
- The temperature limit control or fuel limit switch

Gravity warm-air systems. Because there are no moving parts in the gravity warm-air system except the dampers, maintenance problems are minimal. Most gravity flow systems now in service are old coal burners converted to gas. The foremost consideration when maintaining these systems is ensuring proper firebox conditions, such as draft, fuel quality, and fire size.

Hot-water systems. Each radiation unit should be vented of accumulated air on a regular basis.

Pressure-atomizing burners. The user should refer to the manufacturer's instructions for routine inspection and maintenance. Oil pumping failure is a common problem and frequently causes inadequate performance. When the burner is running and no fire results, maintenance checks that should be considered are the following:

- Check all valves on suction and feed lines to be sure that they are open.
- Check supply of the oil tank.
- Check vacuum on suction line.
- Check lines for obstructions.
- Check the viscosity of the oil. Ensure that it is within the manufacturer's recommendations.

If performing these items does not locate the cause, additional troubleshooting might be needed and should be performed in accordance with the manufacturer's recommendations.

Gas-fired units. Typical maintenance activities include lubricating the motor (in accordance with the manufacturer's recommendations). Heat exchanger tubes can be cleaned through the bottom of the unit by removing the bottom pan and burners. A wooden lath or a wooden stick shaped to fit can be pushed up and down along the sides of each tube to free the soot. Additional maintenance activities can include the following:

- Clean the pilot burner orifice with compressed air or by passing a wire through it.
- Clean solenoid valves by removing any foreign matter from the valve disc and plunger assembly.
- Check the operation and cleanliness of the pilot safety valve.
- Ensure safe operation of the pilot safety switch.
- Adjust or replace the overheat control limit switch.

Oil-fired units. After cleaning burner pots, check fuel line connections for leaks. Keep all connections tight. Remove any excess carbon found in the combustion chamber or on the burner equipment. Remove and clean the unit, both inside and out, and remove accumulations of soot in the flue pipes. Remove and service the burner pilot assemblies. Clean all air holes of the pot using a tough copper wire. After inspecting the pot for warped or deformed surfaces and burned-out sections, which can cause loose connections and dangerous leaks, readjust surfaces and replace the parts if heat and wear have caused irreparable damage. Touch up worn exterior surfaces with matching paint.

Electric heaters. Check and calibrate the thermostat according to the manufacturer's instructions. Replace any burned out bulbs and check the safety light to ensure that it is operational. Ensure that no dust or other foreign matter is allowed to collect on the heating units. Lubricate motors and fans according to the manufacturer's instructions. In insulations that use belt drives, check the lower pulley to ensure that it is in alignment at all times and that the motor shaft and blower shaft are parallel in order to have the grooves of each pulley in realignment. Replace worn or loose belts as needed.

Steam units. To maintain maximum performance, keep heating elements free of dirt, grease, and other foreign particles in the air. Clean heating elements at least once a year; if operating conditions are poor, clean the elements more often. If corrosive fumes are present, examine and clean the coil frequently. Remove and clean the strainer basket annually. Replace damaged strainer baskets immediately, because large holes permit scaled dirt and rust into the steam trap. Disassemble the trap according to the manufacturer's instructions in order to check the operation of the float linkages. Replace defective parts if the linkage does not operate freely. Clean the contacts of the thermostat with fine sandpaper. Replace any thermostat that cannot be adjusted properly.

5.3.2.3 Water Heaters

General routine maintenance for various types of water heaters typically includes several activities.

Lubrication. Lubricate the motor of the oil burner and the moving parts of mechanical devices.

Rust and corrosion. Remove rust and paint bare spots and corroded areas, where needed.

Automatic controls. Check the accuracy of thermostats by sling psychrometer or by wet- or dry-bulb mercury thermometer; make adjustments to attain normal performance.

Thermal insulation and protective coverings. Replace or tighten fastenings; make minor repairs.

Burner assemblies. Test heating output at each step of multiple-step heating levels; tighten loose connections; repair or replace damaged or missing parts; adjust fuel/air mixture to produce blue flame; adjust pilot light; replace black or burnt-out pilot lamps; reset baffles; clean heat-transfer

surfaces and ignition devices; correct misalignment; clean openings in jets, orifices, and valves; and replace dirty oil filters, defective oil burner, and other parts of assemblies.

Combustion chambers. Tighten loose connections, clean ash pits and grates, and make minor repairs.

Electrical heating elements and controls. Tighten loose connections, repair contact springs, clean contacts, replace defective fuses, and make other minor repairs.

Gages. Remove and calibrate gages, instruments, and protective devices.

Water compartments and tanks. Tighten connections where feasible, and replace deteriorated anodic rods or segments.

5.3.2.4 Pneumatic Systems

Reciprocating compressors. The manufacturer's recommendations should be followed regarding the frequency of lubrication, the quality of the lubricant, and the packing. Periodically, clean cylinder jackets of a water-cooled compressor. Dirt accumulations interfere with the water circulation. Replace defective valve parts as required. When replacing worn piston rings, try the new rings in the cylinder for fit. If the cylinder wall is badly scored or out of round, rebore the cylinder; replace the cylinder linings if they are pitted. Before installing the new rings, clean the ring grooves, and remove all carbon deposits. Check piston and clearances after replacing pistons or after adjustment or replacement of main, crank pin, wrist pin, or cross head bearings.

Rotary sliding-vane compressors. Replace the rotor blades if the blade thickness at any point is found to be less than 85% of the width of the rotor slot or if the blade width is found to be less than 90% of the rotor slot depth. Thoroughly clean the cylinder and terminal annually. Blow out all oil holes, and ensure that they are open and free of sludge. Flush out cylinder jackets with a water hose to remove dirt accumulation. Stone rough spots and cylinder walls, cylinder heads, and rotor. Replace defective gaskets. Replace worn or defective bearings as required in accordance with the manufacturer's instructions. Each time the compressor is inspected internally or disassembled for repair, inspect and maintain the clearances according to the manufacturer's recommendations. Follow the manufacturer's instructions for intervals and quality of lubrication.

Rotary twin-lobe compressors. Timing gears should be securely locked to their shafts in proper position. Clearances should be in accordance with the manufacturer's instructions. Keep seals free of dust and dirt to ensure a long service life, and carefully follow the manufacturer's instructions when replacing mechanical seals.

Rotary liquid-piston compressors. Follow the manufacturer's instructions for intervals and quality of lubrication. When replacing packing, thoroughly clean the stuffing box of old packing and grease. Cover each new piece of packing with the recommended lubricant. Replace worn or defective bearings as required in accordance with the manufacturer's instructions.

Dynamic compressors. Clean oil filter and strainers every three months or as needed. Replace filter cartridges when required. Use the quality of oil recommended and replace oil at the intervals specified by the manufacturer. After checking oil pumps for corrosion, erosion, and wear, repair or replace parts as needed. Check the alignment of the unit with a dial indicator. To correct axial misalignment, add or remove shims under the driver to bring the compressor drive center lines into alignment. To correct angular misalignment, parallel the coupling faces by shifting the drive on its base and adding or removing shims under the driver base.

If the compressor is operating inadequately, or if noise or overload conditions indicate internal trouble, dismantle the compressor and inspect as follows:

- Examine the casing or stator for corrosion, erosion, or dirt. Check for evidence of leaks if diaphragm cooling is provided.
- Inspect rotor for corrosion or for erosion to impellers or blades. Check rotor for balance.
- Check clearance or rotor bearings and seals.

Intake filters. After inspections, clean air filters when necessary. On oil-bath-type filters, remove sludge when it has accumulated to a height of 1/4 in. in the sump. If a thickening of the oil is noted, change the oil even if excessive sludge is not present, because thickened oil prevents proper oil circulation in the filter. Clean the air intake filter element and drain all oil. Thoroughly clean out all sludge accumulations. Clean the filter element by agitating it in a solvent or a hot-water and detergent solution. When the filter element is dry, recharge with clean oil by dipping, brushing, or spraying. Use the quality of oil recommended by the manufacturer.

Silencers. Semiannually, clean silencer internals for dirt accumulations. Replace defective gaskets as required.

Intercoolers and aftercoolers. Clean tube interiors by flushing a stream of water through them. More persistent deposits might require the use of brushes, rods, or other cleaning tools. Clean tube exteriors by hosing with hot water. A stiff-bristle brush aids in removing deposits from between tubes. Clean cooler interior without dismantling the unit by passing a chemical solution through it. The solution should dissolve the scale or other deposits without attacking the metal. Thoroughly wash out all chemicals from the cooler before returning it to service.

Separators. Drain separators regularly if automatic drainers are not provided. Frequency of draining is best determined by experience with the installation. Improperly drained separators result in moisture carryover into the air distribution system.

Traps. Thoroughly clean trap interior at least once a year. Frequency of cleaning depends on the condition of the system and whether a strainer is installed ahead of the trap. Remove all dirt accumulations from the trap body and mechanism, using a solvent if necessary. Clean valve seats using a small spiral brush.

Absorption-type air dryers. Semiannually calibrate instruments. Lubricate and repack valves as required. Repair all leaks. Repair or replace defective controls and instruments. Paint dryer towers

and piping when necessary. Replace desiccant if it is dark brown or black or gummy. (A light brown color or slight discoloration does not indicate the need for replacement.)

Refrigeration-type air dryers. Clean or replace filter element as required. Clean deposits from condensation collection chamber and condenser evaporator tubes with compressed air or steam. Lubricate and repack valves as required. It is not recommended that facilities maintenance personnel attempt to service the heat or refrigeration unit.

5.3.2.5 Steam Distribution Systems

On a monthly basis, inspect for correct operation of equipment such as steam traps, pumps, pressure and temperature controllers, and strainers. Repair all pipe leaks immediately by tightening loose connections, tightening or repacking valve glands and conduit-walled glands, replacing gaskets, and welding or replacing defective parts or sections. Repair the coatings and covering of protected metallic conduits as necessary. If the area to be repaired is small, use a standard asphalt blanket patch, and cut to cover the required area. For larger areas, a canvas blanket covered with hot asphalt is an effective repair procedure. Replace damaged insulation and repair leaks of metallic conduits by caulking, peening, or welding. If required, replace defective sections.

Provide and maintain good water drainage. Use proper gasket material of correct design for the flue pressure and temperature service conditions. Control corrosion of the lines.

Repair or replace supports, hangers, guides, expansion joints, and auxiliary equipment as required. Make repairs to manholes as required following periodic inspections. Correct water leaks in the floors and walls as needed.

5.3.2.6 High-Temperature Water Distribution Systems

The maintenance procedures for high-temperature water distribution systems are essentially the same as those provided for steam distribution systems.

5.3.2.7 Instruments and Controls

Maintenance of instruments. After the yearly inspection, repair or replace defective parts as necessary in accordance with the manufacturer's instructions. Typical repairs are the following:

- Replace bourdon tube assemblies distorted from overpressure.
- Replace temperature bulbs that are swollen as a result of excessive temperature.
- Replace all gage movement linkages, pins, and bushings that have lost motion due to wear.
- Replace or repair broken adjustment assemblies.
- Clean dirty mercury by straining it through chamois cloth.
- Repair all leaks in piping or meters.

- Repair or replace defective floats.
- Replace defective gaskets.
- Rod out all plugged or partly plugged pipeline connections.
- Clean out the meter-connecting piping.
- Lubricate according to the manufacturer's instructions. Use recommended lubricants.
- Replace all corroded, bent, or otherwise defective parts.

Maintenance of controls. After the yearly inspection, repair or replace defective parts as necessary in accordance with the manufacturer's instructions. Perform the following maintenance as required:

- Examine the regulating valve stem and valve plug and seat, and replace them if necessary. Change the valve to a smaller size if excessive cutting indicates that the valve is oversized. Check valve position and spring adjustment. Repack stuffing box.
- Clean, inspect, and test needle, pilot, poppet, and reducing and transfer valves. Replace defective parts.
- Observe condition of bellows and diaphragms. Replace if defective.
- Replace gaskets.
- Replace worn linkage pins and bushings.
- Clean air filter. Replace air filter cartridges.
- Repair all leaks. Rod out piping connections when necessary.
- Vent out air from liquid-filled systems.

5.3.2.8 Air Conditioning Systems

Lubricate as required; add lubricant if grease dispenser or oil cup is less than half full; add oil to crankcase or refrigerant compressor if below correct level, and change if dirty; and clean clogged oil lines. Remove rust and paint bare spots and corroded areas. Table 5-4 lists component level maintenance activities for air conditioning systems.

Table 5-4
Recommended Maintenance for Air Conditioning System Components [1]

System Component	Recommended Maintenance Activity
Compressors	Remove dirt, dust, and other accumulations. Use halide torch to check refrigerant leaks, and watch for flame color change indicating a leak. Tighten loose connections, belts, and parts. Replace worn belts. Correct misalignment and make other minor repairs.
Motors, drive assemblies, and fans	Remove accumulations. Tighten loose connection and parts. Tighten loose belts and replace multiple belts in sets when one is worn. Replace defective brushes. Make other minor repairs and adjustments.
Air ducts, dampers, registers, grills, louvers, and screens	Remove deposits. Tighten or replace defective connections and parts. Caulk around flashings and make weather tight. Adjust damper settings. Make minor repairs and adjustments.
Wiring and electrical controls	Tighten loose connections and parts. Replace cords with wet insulation or where broken in two or more places, and replace braid that is frayed more than 6 in. Replace or adjust contact springs. Clean contacts. Replace defective or improper fuses.
Steam and hot-water heating units	Clean heat-transfer surfaces. Tighten loose connections and parts. Replace leaking valve packing. Close bypass valves; clean valves, traps, and strainers.
Thermal insulation and vapor barriers	Repair or replace to restore insulating properties.
Air filters	Replace dirty throwaway-type filters and those missing or with improper fit. Wash permanent-type filters in soapsuds or solvents and rinse with hot water. Restore viscous coating in accordance with the manufacturer's instructions.
Guards, casings, hangers, supports, platforms, and mounting	Tighten loose connections and parts. Adjust level. Replace defective sound insulation. Make minor repairs and replacements.
Temperature and humidity controls	Adjust settings. Tighten connections. Clean contacts and adjust alignment.
Electrical heating units	Clean contacts and heat-transfer surfaces. Tighten loose connections. Make minor repairs and adjustments.

Table 5-4 (cont.)
Recommended Maintenance for Air Conditioning System Components [1]

System Component	Recommended Maintenance Activity
Pump units	Clean, repair leaks, and make other minor repairs.
Piping	Repair leaks and make minor repairs.
Water sprays and weirs	Remove external scale. Tighten leaky connections. Replace defective gaskets. Adjust float valve. Clean clogged openings with wire. Position nozzles and adjust baffles or eliminators. Make other minor repairs.
Shell- and tube-type condensers	Remove dust accumulations as needed.
Cooling coils	Clean out dust, particularly between fins, using vacuum cleaner or brush. Straighten bent fins. Correct level. Remove obstructions from air flows. Make adjustments and repairs.

5.3.3 Electrical Systems

5.3.3.1 Electrical Distribution Systems

Wiring. Any type of wiring, provided it is in accord with the applicable codes and standards and satisfies the functional requirements of the facility, is suitable for repair or replacement. Maintenance of wiring is minimal, and, in addition to the routine inspections described in Section 4, typically consists of replacement of discrete electrical components and faulty sections of wire.

Ducts and trays. Any ductwork that is found to be damaged due to such factors as corrosion or operational abuse should be replaced. Underfloor conduits and duct systems should be kept sufficiently clear of electrical and hot-water floor-heating systems to prevent undue heating of the enclosures. Bus ducts, trolley ducts, and open bus ways require annual cleaning and removal of oil substances and dirt. Ventilated-type bus ways should have the buses blown off annually with clean and dry compressed air.

Fuses. Fuses should be replaced when there is evidence that the fuse has blown or where there is evidence of cracked insulators, breaks, or burns.

Circuit breakers. In most cases, if a circuit breaker has been opened due to an overload, all that is necessary is to reset it. At times, however, the overloaded circuit breaker must be replaced, which is typically more costly than replacing a comparable fuse. Table 5-5 describes some common maintenance and repair procedures for circuit breakers.

Table 5-5
Common Maintenance and Repair Procedures for Circuit Breakers [1]

Operational Problem	Maintenance or Repair Procedure
Failure to trip or close	Replace blown fuse. Repair faulty wiring, ensure that all binding screws are tight. Clean dirty contacts.
Unnecessary tripping	Set relay or device for proper value according to ampere load of the circuit.

Switches. Knife switches can require realignment of blades and jaws. If the jaws of a switch become annealed as a result of overheating, poor contact results and they should be replaced. Annealed jaws can be protected by tapping with an insulated object when the blade is open. If the jaw rings on being tapped, it is not annealed; if a dull, dead sound results, it is annealed. The frequent operation of the switch prevents oxidation of the blades.

Excessive deposits of dust and dirt in the operating parts of the switch invariably cause binding of shafts, triggers, rollers, and pins as well as the operating levers. All insulating surfaces should be kept clean in order to prevent electrical breakdown.

Cabinets. Cabinets should be kept locked to prevent tampering by unauthorized personnel. In large cabinets, the presence of moisture or humid conditions can require installation of strip heaters to maintain a temperature that inhibits condensation when the equipment is not operating. When panel enclosures are exposed to corrosive fumes, they should be painted with an acid-resisting paint. The areas around all enclosures should be kept free for emergency servicing. Circuits should be numbered in a suitable directory provided on the inside of the lower door of the cabinet.

5.3.3.2 Lighting Systems

Careful observation by all maintenance personnel is needed to discover and report any evidence of defects in lighting systems. Maintain the required illumination intensity by keeping lamps, fixtures, and reflective areas clean and in good repair; replace defective lamps and keep the voltage steady. The progressive decrease of light caused by accumulation of dirt necessitates periodic cleaning of lighting equipment. The frequency of cleaning depends on local conditions. The cleaning schedule for a particular installation should be determined by a light meter reading after the initial cleaning. When subsequent footcandle readings have dropped 20–25%, the fixture should be cleaned again. Lighting equipment should be washed, not just wiped off with a dry cloth. Washing reclaims 5–10% more light than dry wiping and reduces the possibilities of marring or scratching the reflective surfaces of the fixture.

Removable glassware, counter reflectors, and diffusing louvers should be cleaned by immersing them in a solution of synthetic detergent cleaner and scrubbing with a soft brush or sponge. If steel wool must be used, it should be of a Number 0 or finer grit. The fixture should then be rinsed in clear warm water and dried with a clean cloth. If the equipment is fixed, it should be wiped with a moist cloth or sponge, using a solution of synthetic detergent cleaner. If steel wool is

required to remove the dirt film, use Number 0 steel wool. Wipe off the excess moisture with a clean cloth. Enamel, chrome, aluminum, or silver-plated reflecting surfaces that cannot be adequately cleaned and polished should be replaced.

Neglected lamp outages reduce illumination. Lamp replacement is done by either an individual or group method. Additional maintenance activities for lighting equipment are provided in Table 5-6.

Table 5-6
Routine Maintenance of Lighting Equipment [1]

Lighting Problem	Maintenance Activity
Incandescent Lamp Equipment	
Lamp loose, burned out; loose or broken connections	Tighten lamp in socket, replace with new lamp, secure terminals, or repair wiring.
Low voltage	Match lamp rating to line voltage or increase line voltage.
High voltage, mechanical damage, incorrect lamp, or excessive vibration	Match lamp rating to line voltage or improve regulation to avoid surges. Replace lamp, ensure that water does not drip on bulb, and use rough service lamps if needed. Alleviate source of vibration on the lighting equipment.
Water contacting bulb or physical damage	Replace with enclosed, vapor-tight luminaire.
Fluorescent Lamp Equipment	
Lamp pins not contacting, lamp at end of life, defective starter, low line voltage, fault in circuit of luminaire, or low temperature of surrounding air	Seat lamp firmly and correctly, replace with tested bulb, replace with tested starter, match lamp rating to line voltage or increase line voltage, check wiring and lamp holders, shield lamp from drafts, enclose lamp to conserve heat, and use thermal-type starters.
Cold or too-rapid starting	Replace starter.
Poor ballast, faulty starter, or improper wiring or ground	Check ballast, replace starter, and check wiring and ballast for ground.
Improper starting, low line voltage, or poor lamp holder contact	Replace starter, increase voltage, seal lamp firmly in lamp holder, and check ballast and wiring.
Improper installation, line feedback, or poor ballast	Replace ballast.
Mercury Lamp Equipment	
Lamp loose, lamp burned out, low voltage, wiring fault, low temperature, or fluctuating voltage	Tighten lamp in socket, replace lamp, connect line to transformer tap closest to line voltage, increase line voltage by changing transformer tap, and tighten wiring connections.
Wiring fault	Tighten connections, check wiring, and separate lighting circuits from heavy power circuits.
Improper supply connections or inadequate incandescent luminaires in the system	Where there is a three-phase supply, connect luminaires on alternate phases. On single-phase supply, add incandescent luminaires to the system.

5.3.3.3 Motors

Routine maintenance of motors consists basically of cleanliness and lubrication. A dirty motor runs but at higher than normal temperatures, which tends to shorten the life of both the insulation and the motor. Table 5-7 provides a list of common maintenance and repair procedures for ac/dc motors.

Table 5-7
Routine Maintenance and Repair Procedures for ac/dc Motors [1]

Operating Problem	Maintenance or Repair Procedure
Hot bearings (general)	• Decrease belt tension. • Move pulley closer to bearing. • Use larger pulleys.
Hot bearings (sleeve type)	• Use a lighter oil. • Use a heavier oil. • Fill reservoir to proper level in overflow plug while motor is at rest.
Hot bearings (ball type)	• Maintain proper quantity of grease. • Reduce quantity of grease. • Protect bearing by reducing motor temperature. • Check alignment, side thrust, and end thrust.
Oil leakage from overflow plugs	• Remove, recement threads, replace, and tighten. • Replace the plug. • Install cork gasket, or if screw-type, tighten.

Table 5-8 provides a list of common maintenance and repair procedures for dc motors.

Table 5-8
Routine Maintenance and Repair Procedures for dc Motors [1]

Operating Problem	Maintenance or Repair Procedure
Motor fails to start	• Switch open, leads broken. • If held up by brush springs, replace. • Replace brushes. • Remove and sand, clean up brush box. • Check line connections to starter, and check contacts in the starter.
Motor starts, then stops and reverses direction of rotation	• Check generating unit for cause of changing polarity. • Reconnect either the shunt or series fields in order to correct the polarity. Check the connect armature leads for desired direction of rotation. The fields can be tried separately to determine the direction of rotation individually and connected so that both give the same rotation.
Motor does not come up to rated speed	• Check bearing condition and lubrication. Check driven load for excessive load or friction. • Measure voltage with meter and check with motor nameplate data. • Check for factory setting of brush rigging or test motor for true neutral setting. • Increase load on motor to increase its temperature, or add field rheostat to set speed.

Table 5-8 (cont.)
Routine Maintenance and Repair Procedures for dc Motors [1]

Operating Problem	Maintenance or Repair Procedure
Motor runs too fast	• Reset neutral by checking factory setting mark or testing for neutral. • Measure voltage across field and check with nameplate rating.
Motor continually runs too slow	• Measure voltage and try to correct to value on motor nameplate. • Check condition of bearings and the drive and check for excessive friction in drive. • Check for factory setting of brush rigging or test for true neutral setting.
Motor overheats or runs hot	• Reduce load by reducing speed or gearing in the drive or by loading in the drive. • Motor runs drive above rated speed requiring excessive horsepower, reduce voltage to nameplate rating. • Location of motor should be changed, or restricted surrounding removed; if covers are too restricting, they should be removed or modified. Open motors cannot be totally enclosed for continuous operation. • Check brackets or pedestals to center rotor and determine condition or bearing wear for bearing replacement.
Hot armature	• Limit pressure to 2 to 2 1/2 psi. Check brush density recommended by the brush manufacturer.
Hot commutator	• Reset neutral. • Check as for hot motor.
Hot fields	• Check with meter and thermometer and correct voltage to nameplate value. • Check as for hot motor.
Motor vibration	• Tighten pulley on shaft or correct eccentric pulley. • Adjust belt tension. • Stiffen mounting place members. • Tighten hold-down bolts. • Add shims under foot pads to mount each foot tightly.
Motor sparks at brushes or does not commutate	• Check and set on factory setting or test for neutral position. • Maintain brushes as noted.
Excessive brush wear	• Blow dust from motor and replace brushes with a grade as recommended by the manufacturer. • Recheck factory neutral or test for true neutral. • Adjust spring pressure not to exceed 2 to 2 1/2 psi.
Motor noisy	• Tighten foundation bolts. • Coat underside with soundproofing material. • Shim motor feet for equal mounting. • Check condition of belt and change belt tension.

Table 5-9 provides a list of common maintenance and repair procedures for ac motors.

Table 5-9
Routine Maintenance and Repair Procedures for ac Motors [1]

Operating Problem	Maintenance or Repair Procedure
Motor stalls	• Change type or size. • Reduce load. • Ensure that nameplate-rated voltage is maintained. • Fuses blown: check overload relay, starter, and push button.
Motor runs and then dies down	• Check for loose connections to line, fuses, and control.
Motor does not come up to speed	• Check load that motor is supposed to carry at start.
Motor takes too long to accelerate	• Reduce load. • Check for high resistance. • Replace with new rotor.
Motor overheats while running under load	• Reduce load. • Check adequacy of air ventilation. • Check for faulty leads, connections, and transformers. • Check terminals of motor with voltmeter.
Motor vibrates after corrections have been made	• Rebalance driven equipment.
Unbalanced line current on polyphase motors during normal operations	• Check leads and connections. • Ensure that brushes are properly seated and that shunts are in good condition.
Contactor or relay does not close	• Check fuses and disconnect switch. • Check power supply (wire size might be too small).

5.3.3.4 Batteries

Measures that should be included in a battery maintenance program are the following:

- Keep the battery properly charged. Overcharging or undercharging should not be done. Ideally, charge the battery on a daily basis.
- Use either distilled or demineralized water, depending on the manufacturer's recommendations. Keep water at proper levels according to the manufacturer's recommendations; the low-level point is at the top of the separators and the high point is usually 1/16 in. below the bottom of the filling tube. The level of water should be between these points. Check the water level on a weekly basis and add water as needed.
- Keep the battery clean and dry, and wash it down on a weekly basis.
- Keep battery temperatures at the manufacturer's recommended levels.
- Keep metal objects and tools away from battery surfaces to prevent shorts.
- Keep open flames away from the top of batteries to prevent explosions.

- Clean and neutralize the vent plugs on a monthly basis.
- Add acid based on the manufacturer's recommendations.

5.3.3.5 Transformers

The size, importance, and location on the system; ambient temperatures; and the surrounding atmosphere typically govern transformer maintenance. A transformer typically requires little preventive maintenance; but when a transformer winding fails, immediately disconnect it from the power source. Indications of such a failure are smoke or liquid, which can be accompanied by noise, coming from the tank. Do not reenergize the transformer if it has been established that a winding has failed.

After neutralizing the transformer from its power source, conduct inspections and tests in strict accordance with the manufacturer's recommendations. As a minimum, these diagnostic tests can include the following:

- Check for external damage to bushings and leads.
- Check the level of liquid in all compartments.
- Check the liquid temperature.
- Check for evidence of leakage.
- Check for evidence on the primary and secondary sides of the transformer for the cause of the failure.

Depending on the result of these tests and inspections, corrective maintenance should be conducted in accordance with the manufacturer's recommendations.

5.3.3.6 Alarm and Public Address

Because of the varied types and designs available, the maintenance and repair of these devices vary extensively. Therefore, maintenance of these system components should be done in accordance with each manufacturer's recommendations.

5.3.4 Conveying Systems

In general, the maintenance and repair of these devices vary extensively because of the various types and designs available. Therefore, maintenance of conveying systems should be done in accordance with each manufacturer's recommendations. Aside from the inspection activities noted in Section 4, preventive maintenance of these systems typically includes cleaning, lubrication, and replacement of worn or damaged parts.

5.4 Routine Maintenance of External Systems

5.4.1 Walks, Drives, Curbs, and Asphalt Surfaces

Keeping asphalt walks and drives clean and in good repair is of utmost importance, because they serve as a means of getting to and from the building. In order to keep repairs to a minimum, it is important to follow certain precautions relative to maintenance of the surface. The first of these is to refrain from applying harmful chemicals to the surface: a) do not use salt on concrete to melt snow or ice, and b) do not spill gasoline, kerosene, or other such liquids on asphalt surfaces.

Secondly, place a protective covering over asphalt surfaces when working on them to protect them from accidental spillage of chemicals that might damage to the surface. If an accidental spill occurs, immediately wash down the surface with water and a neutral detergent. Aside from regular semiannual inspection, maintenance of asphalt surfaces typically includes performing repairs on an as-needed basis, as described in Section 6.

5.4.2 Runoff, Drainage, and Erosion Control Systems

5.4.2.1 Drainage and Erosion Control Systems

Maintenance of these systems should focus on the control of erosion. Erosion can be decreased by reducing the velocity of surface-water runoff. Vegetation cover is one of the best ways of doing this. This is particularly important in natural or artificial waterways. It is also important to reduce the volume of water flowing from higher ground.

Vegetation covers are the least costly and most effective dust control method, and they also assist in the prevention of water erosion. They cushion the impact of the raindrops and prevent blasting of the soil particles into the air. The stems slow up the movement of water, and the roots bind the soil particles together. This promotes the seepage of rainfall into soil. Local or native grasses that grow even in arid regions and sandy soil can usually be found. Typical vegetative covers include perennial grasses, trees, shrubs, and vines.

5.4.2.2 Drainage and Erosion Control Structures

In general, drainage facilities should be kept free of silt bars, snags, vegetation, logs, tree branches, and other debris that encourage silt disposition. Where silt must be removed, trace the source of the silt and take corrective measures to prevent reoccurrence. Maintenance and corrections normally required include the following:

- Clean inlets, catch basins, culverts, storm drains, ditches, and under drains.
- Restore and restabilize the structure.
- Make minor modifications to existing waterways and structures.

Open-earth channels. When stabilized by vegetation, channels with side slopes of 3:1 or flatter can be maintained by mechanized equipment. Recurrent maintenance (seasonal and emergency) of open-earth channels is required to remove plant growth, rock, and soil deposits and to make other repairs to maintain flow. Maintenance projects involving open-earth channels, lined channels, or other structures should not be performed without appropriate engineering involvement.

Vegetated channels. Many of these are plowed out, and soon after the vegetation is destroyed, they become large gullies. If damaged areas or vegetative waterways are to be reseeded or resodded, ensure that all fill materials are properly compacted to provide good seedbed and to reduce erosion during the period of vegetation establishment. When these waterways are to be vegetated by seeding, securely anchored mulch or other protection is usually required until vegetation becomes established.

Lined channels. Lined ditches should be kept clean and free from debris, silt, and weed growth. When installing rip rap or pipe lining, ensure that it is high enough and wide enough to prevent washing and undermining of the edges.

Bank protection. Vegetative cover should be established for the protection of the bank slopes. Under some conditions, the banks can be stabilized by planting willows or other vegetation. Grass covers are usually the most desirable, but vines or shrubs are more satisfactory for larger channels. When established, the vegetation should be maintained as prescribed for semi-improved areas. Large ditches, which carry continuous flows, should be cleared of any vegetative growth in the bottom. However, vines, mats, or perennial grass coverings of the sides should not be removed because they offer protection against erosion and bank cutting. Vegetation should be allowed to grow in the back of revetments, jetties, and areas where silt deposition occurs, as well as on slopes protected by brush mats.

Dikes and levies. Levy maintenance is the same as for most fill and/or slopes, but special attention should be given to forestall failures. Also important are rodent control and consideration of automatic plug gates or pumps to remove excess water from protected areas.

Tile drains. Ensure that all outlets remain open and that adequate head walls and catch basins are sound. Open and clean plugged lines or, where necessary, replace with larger tile and correct the tile grade. Clean out tile lines that are filled with tree roots.

Check dams. Maintenance of these structures typically includes the following:

- Remove rank growing vegetation.
- Repair erosion damage.
- Place fill to raise low points in the crest of the dam.
- Fill holes and cracks in the dam.
- Relieve seepage pressures by laying a blanket of impervious material on the upside of the dam.

Manholes, inlets, and catch basins. Recommended maintenance of manholes, inlets and catch basins includes the following:

- Check the inlet and barrel of the culvert. Keep them free of logs and debris.
- Fill any holes in or near the inlet, and plant vegetation as needed.
- Remove or trim rank vegetation, such as large roots, that grows in the vicinity of the inlet.
- Repair or replace deteriorated mortar and loose, broken, or displaced brick. Remove all sand, mud, grit, or other debris.
- Remove corrosion on ladders and steps, and repaint with a rust-resistant paint as needed. Repair or replace loose, broken, or damaged ladders.
- Repair or replace damaged, missing, or corroded frames and covers. Reseat manhole covers as necessary.
- Make necessary repairs of bonding where storm sewer piping joins the manhole wall.
- Realign pipes that have become misaligned due to settlement.

Culverts and outlet structures. Proper maintenance of outlet structures is similar to that for other drainage facilities. The type and degree of maintenance varies with the type of outlet.

Tide gates. Care should be taken to keep the channel clear of all debris so that the gate does not become jammed open and fail to operate properly with the incoming tide. The seaward side of the gate should also be kept clear so that the gate opens and releases the retained water. Care should be taken to prevent accumulation of debris both in the channel and in the seaward side of the spearhead.

Drop spillways. Regardless of the type of inlet used, care should be taken to keep the apron and the spilling basin free of all foreign elements that might prove detrimental to maximum efficiency. General maintenance for drop spillways should parallel that for inlet and outlet structures, with special consideration given to the following:

- Repair chips and cracks in the concrete.
- Repair settlement of part or all of the spillway.
- Correct for erosion loss of inlets and aprons or for spilling basins.
- Correct for erosion of the soil around inlets, aprons, head walls, and wing walls.

Storm sewers. In general, the routine maintenance of storm sewers includes cleaning, flushing, and all the necessary repairs to defective lines and structures. A good rule of thumb is to clean at least one-third of the entire system on an annual basis.

Hillside diversions. Typically, special erosion-control grasses are used in these waterways. As such, they require heavy fertilization and frequent mowing if a uniform erosion-resistant cover is to be maintained throughout the year. Where concrete or other erosion-resistant linings are used in these channels, it is important to prevent erosion along the sides and underneath the flume lining.

Side erosion is reduced by maintaining small berms that divert surface water away from each side of the flumes.

Diversion ditches. Vegetation should be maintained in areas above the diversion ditches so that runoff does not carry large amounts of silt into the channel. Regular maintenance prevents bushy or woody growth from obstructing flow and causing silt to accumulate.

5.4.3 Fences

Metal fences are either aluminum or steel. Maintenance of steel fences involves protection against rust or other damage. Except in highly corrosive climates, such as seaside locations or certain industrial areas, maintenance, as far as rusting is concerned, is not a major problem. Aluminum fencing usually requires little attention. However, repairs to fencing damaged by accident or vandalism are often necessary. Generally, maintenance of metal fences involves painting to prevent rust or corrosion; keeping the fence material, ties, and braces in place; keeping the fence posts straight and firmly anchored in the ground; ensuring that the gate is hung properly without sagging; filling holes under fences; and keeping the fence line free of vegetation or trash.

Maintain gates so that they operate easily and close properly without binding. Maintain hardware in working condition and replace missing parts as soon as possible. Pull sagging gates back into shape, and brace them by wires or rods with turnbuckles so that adjustments can be made as necessary. Keep parts such as hinges and brackets tight to prevent wobbling of the gate or interference with its operation. Lubricate wheels and pulleys of sliding gates as needed. Keep tracks straight, clean, and level.

For electric fences, the wire must be firmly attached to the insulation, which, in turn, should be firmly attached to the wooden posts. Check the batteries and power supply on a regular basis to see if proper voltage and current are being maintained. Replace broken wires and insulation in order to keep the fence operable.

Fence painting is expensive, and in certain cases, cannot be economically justified. Repeated painting of fences can soon equal or exceed the cost of replacing the fencing. Fences that are properly inspected and maintained last for years without more than occasional spot painting.

5.4.4 Tanks

Preventive maintenance for aboveground or elevated tanks can include the following:

- Drain, flush, and clean the interior walls of the tank.
- Repair the internal lining of the tank with an appropriate/equivalent lining material/coating.
- Coat the exterior of the tank with an appropriate coating material.

6
CORRECTIVE MAINTENANCE AND REPAIRS

6.1 Repairing Major Structural Materials

6.1.1 Repairing Reinforced Concrete

6.1.1.1 Pre-Repair Considerations

When selecting an applicable repair procedure, consider the resulting appearance. When patching, the following precautions should be taken when the appearance of the concrete is important:

- Use concrete that has qualities similar to those of the surrounding concrete.
- Finish the patch in the same manner as the surrounding concrete.
- Try a sample patch before patching the actual structure.
- It is usually best to not patch.

For extensive repair areas, the following precautions should be considered:

- Large areas can be broken up into small units, each unit at a different level. This gives an ideal appearance.
- All repair work must be uniform in both materials and workmanship.
- Use construction joints only in approved areas.
- Consider the use of a brick or stone facing after the repair has been made.

Admixtures. The second factor that must be considered during the pre-repair stage is that many repairs incorporate the use of concrete admixture, which is a chemical that adds some desired effect to the concrete. Commonly used admixtures include:

- Air-entrainment agents
- Retarder and densifying agents
- Cure-acceleration agents
- Expanding mortars
- Waterproofing agents

Preparation. First remove all damaged, loosened, or unbonded portions of existing concrete by chipping hammers or other approved equipment. Then prepare the surfaces by wet sandblasting, waterblasting with approved waterblasting equipment, and bush hammering—or any other approved method—and then clean and allow the surfaces to dry thoroughly. During the process, take care to prevent undercutting aggregate in the existing concrete. Delay replacement of deteriorated concrete several days until a reexamination of excavated surfaces confirms the soundness of the remaining concrete. It is far better to remove too much concrete than too little, because affected concrete generally continues to disintegrate, and, while the work is being done, it costs more to excavate to ample depths. Surface cleaning should be done by air/water jets. Surface drying must be complete and can be accomplished by air jet. Compressed air used in cleaning and drying must be free from oil and all other contaminating materials.

After surfaces have been prepared and properly cleaned, they need to be kept in a clean, dry condition until the placing of concrete has been completed (except for dry-pack repairs). Dry-pack repairs require the application of a mortar bond coat prior to placement of repair material. When a portion of the reinforcing bars is exposed during the preparation process, all the concrete encasing the bar (at least 1 in. all around) should be removed.

6.1.1.2 Repairing Cracks in Concrete

The causes of cracking are poor structural design, movement due to temperature differentiation, overload, and shrinkage during the curing stage. Location, pattern, depth, width, the presence of foreign materials, and elevation differences are all factors that can be used in determining the cause of a crack.

Another factor to be determined is whether the crack is active or dormant. An active crack is due to continuing movement of the structural element for some reason such as foundation movement. A dormant crack can be permanently repaired after the full extent of cracking has occurred. Methods for determining whether a crack is active or dormant are as follows:

- To determine if the crack is progressing along and parallel to its length, mark the end of the crack. After a few days, return to see if the crack has progressed beyond the mark.
- Place a piece of tape that has been notched parallel to the crack, across the crack. If the tape tears or compresses (wrinkles), the crack is active. If there is no apparent change in elongation of the tape after some time, the crack is dormant.
- Apply gauge points, such as pins, on either side of the crack. At regular time intervals, measure the distance between the gauge points, using vernier calipers, to determine if the crack is moving.

Prior to repairing a crack, it must be determined if the crack is of a type that requires only sealing (coating) against intrusion of foreign material and if restoration of structural integrity is required. If the crack is an active crack, perform a stress analysis to determine if strengthening requirements are needed. If the crack is dormant, a factor that should be considered is the occurrence of water in the cracked area and whether or not it must be controlled. Methods of crack repair include acid etching, autogeneous healing, caulking, protective coatings, and concrete replacement.

Acid etching. Typically a commercially available, diluted (to about 10 to 30%) acid is used. The acid is applied by vigorously scrubbing with a stiff wire or fiber-bristle brush or broom.

Autogeneous healing. This is a self-healing-type process in that the cement has the ability to reestablish continuity over a crack by itself. This method is effective for concrete that is in a submerged environment or is exposed to a continuous wash of water.

Caulking. This method uses a high-grade plastic caulk and is applied with a gun or in strips according the manufacturer's recommendations. This method should be used only for dormant- or nearly dormant-type deterioration that is not exposed to abrasive-type loading.

Coatings. The application of coatings to concrete is described in Section 5.

Concrete replacement. This method consists of replacing the defective concrete with ready-mixed or job-mixed concrete of a quality equal to that of the existing concrete. This method is used when the cavity or large crack goes through the entire member, when the concrete is defective beyond the reinforcing steel, or when the depth of the area exceeds 6 in. and the repair will be appreciably continuous. Concrete repairs can be performed with or without forms. Techniques for repairs without forms include the following:

- **Dry packing.** This process involves the placement of stiff mortar by tamping it into place.
- **Grinding.** This method can be used to remove deep-seated stains and irregularities in the surface and as a preparation procedure to receive a repair of a crack.
- **Jacketing.** This process involves applying and fastening a material over the concrete. Common covering materials are metal, rubber, plastic, and concrete.
- **Mortar replacement.** Portland cement mortar can be used for repairing defects on surfaces not prominently exposed where the defects are too wide for dry-pack filling, too shallow for concrete filling, or where they are not deeper than the far side of the reinforcement that is nearest the surface.
- **Slab jacking.** The procedure is used to raise a slab that has settled. Typically, holes are drilled through the slab based on a predetermined pattern established by the engineering organization.
- **Pneumatically applied mortar (gunite).** This method is used for restoration of concrete surfaces where the deterioration is shallow and also for restoring surface spall due to corrosion of the reinforcement.
- **Prepacked or preplaced aggregate concrete.** This technique involves the filling of the area to be repaired with gap-graded aggregate. This is followed by filling the voids with water and then pumping in a sand-cement grout to replace the water-filled voids. This method is used primarily for refacing structures or jacketing or for filling of cavities in and around structures.
- **Stitching.** This procedure is incorporated when major cracks must be repaired and structural integrity reestablished. Holes are first drilled into the concrete on either side of the crack,

using a predetermined pattern. Shaped metal binders called "stitching dogs" are installed across the cracks and into the holes with a nonshrink or expanding grout.

- **Stressing.** This method is used when structural cracks have occurred and the entire area must be strengthened and cracks closed. The process uses stressing cables or rods to apply compression force, which closes the cracks and at the same time increases the structural capacity of the member.
- **Thin resurfacing (bonded or unbonded).** This procedure is sometimes known as an overlay. A bonded type of resurfacing is used if the reason for doing the repair is that wear, such as from abrasion, has taken place.

6.1.1.3 Repair of Water Seepage

When water seeps through the cracks on a concrete surface, it is advisable to place a waterproofing membrane between the old and new concrete. This waterproofing membrane should consist of two layers of roofing felt with hot bituminous material mopped between the layers. The membrane should cover the entire surface and extend a distance of about 12 in. beyond the edge of the surface. Two primary means of repairing concrete from water seepage are sack rubbing and blanketing.

Sack rubbing. This method is used to remove stains or to fill small holes. First, spray the concrete with water. Then rub mortar over the surface and into the voids with a rubber float or a piece of burlap. When preparing the mortar, be sure to add the correct amount of cement to match the existing concrete color.

Blanketing. This is used for large cracks and can be used for sealing active as well as dormant cracks. This is actually a form of coating or overlay, but is used for isolated cracks. If the cracks are active, use an extensible material. For dormant cracks, a brittle material such as mortar can be used. The most commonly used methods of blanketing are the following:

- Elastic sealant
- Mastic-plugged joint
- Crimped water bar-water stops

6.1.1.4 Thermosetting Plastic (Epoxy)

Epoxy should be used to bond new concrete or mortar to old concrete whenever the depth of repair is 1 1/2 to 6 in. Epoxy-bonded mortar should be used to feather the edges when the depth of the repair is less than 1 1/2 in. Epoxies are useful in special applications such as bonding a steel anchor bar in old concrete. Follow the manufacturer's recommendations for the following key steps in using thermosetting plastic products:

- Preparation of the epoxy bonding agent
- Preparation of the epoxy mortar

- Application of an epoxy bonding agent
- Application of epoxy-bonded concrete
- Application of epoxy-bonded mortar
- Application of epoxy by pressure injection

6.1.1.5 Curing the Repair

Because of the relatively small volume of most repairs and the tendency of old concrete to absorb moisture from new material, water curing is a highly desirable procedure, at least during the first 24 hours. When forms are used for repair, they can be removed and then reset to hold a few layers of wet burlap in contact with new concrete. The best method of water curing is a slow soaking from a hose. If curing compound is used, the best combination is an initial water curing period of seven days followed (while the surface is still damp) by a coat of compound. It is always essential that repairs receive some water curing and be thoroughly damp before the curing compound is applied.

Use curing compound whenever there is any possibility that freezing temperatures will prevail during the curing period. Sheet polyethylene should be an airtight, nonstaining, waterproof covering that effectively prevents the loss of moisture by evaporation. Lap and seal the edges of polyethylene. Leave the waterproof covering in place for at least two weeks. If a waterproof covering is used and the concrete is subjected to any usage during the curing period that might rupture or otherwise damage the covering, the covering must be protected by a suitable layer of clean, wet sand or other cushioning material that does not stain the concrete. After curing, remove the covering (except if curing compound is used) and all foreign materials as directed.

Relative to curing epoxy-bonded concrete, when it has hardened sufficiently to prevent damage, moisten the surface by spraying it lightly with water, and then cover it with sheet polyethylene or coat it with an approved curing compound. Epoxy mortar repair should be in accordance with the manufacturer's recommendations.

6.1.2 Repairing Structural Steel

6.1.2.1 Structural Steel Elements

Many repair procedures that are necessary for a facility or building can often be done by maintenance personnel. However, when the integrity of the structure or a structural element is in question, it is of utmost importance that the engineering organization become involved in the design and implementation of the repair. This is especially important because incorrect repair procedures of structural items, such as structural steel, can result in structural collapse or an increased rate of present deterioration.

The three major repair procedures for structural steel elements are:

- Replacement
- Plating
- Encasement

Replacement. Where corrosion or other types of deterioration are severe throughout the structural element, the most economical decision is to replace it. This decision would probably also be made if appearance is a consideration and if there is no room to add plates or strengthening members.

Plating. In most cases, the repair of steel elements involves some degree of strengthening, which can be accomplished through plating. Plating is used when abrasion, corrosion, or other deterioration is localized on the steel members. Plating can also be used for repairing members that have cracked, buckled, or suffered local crushing due to impact. The purpose of plating is to compensate for the loss of the section that has deteriorated away. The process of plating is the splicing in of the new metal across the areas of deterioration. This technique is not applicable where the appearance of plates would be objectionable, in which case, replacement is a better solution.

The material used for plating should be of the same grade as the original structural elements. The original building specifications must be followed when installing the plating material, allowing for close tolerances.

Encasement. The third procedure for repairs is referred to as encasement. This method is considered an indirect repair procedure for steel in that it is performed for the purpose of preventing any new deterioration or further deterioration on a component that has been repaired by plating or has been replaced. The process of encasement is the covering of the existing steel with a covering or encasing it in concrete, bituminous-based material, or other similar substance. Concrete encasement is used when its appearance is not objectionable. This is a very economical and satisfactory method of permanently protecting structural steel.

6.1.2.2 Connections

If the metal adjacent to the fasteners has deteriorated, repairs can be accomplished by plating or replacement. If the fasteners have deteriorated or are extremely corroded, they should be removed, the resulting holes reamed out, and larger or stronger bolts installed. An alternative to bolting is welding the connection.

Loose connections should be given immediate attention. If the connections are bolts, retorque them, unless they are high-strength-type bolts, in which case, replace them. When rivets become loose, replace them with bolts of equal or greater strength. It might be necessary for the existing loose rivets to be drilled out prior to the installation of new fasteners.

Connections of steel members to one another. Whenever two or more structural members are connected, there is the possibility that entrapment of dirt will create a possible corrosion condition. This is especially the case when angles and channels are connected back to back. If deterioration is uncovered during the inspection process, first determine the extent of the damage. If strengthening is not needed, use sandblasting to clean out the deterioration and seal all around the opening.

A more effective repair procedure might be to fill the space between the members with material such as cement grout. However, this type of process is often difficult due to the small confining space between the members. If the deterioration requires strengthening, replacement of plating should be done, making sure that all resulting voids have been sealed or filled, so that future problems with dirt collection are prevented.

Beam- and column-bearing plates. These plates should be checked for pitted surfaces from corrosive action. If such a condition is found, remove the plate, grind it smooth, and replace it. Loss of thickness can be compensated for with the use of metal shims.

6.1.2.3 Specialized Repairs of Structural Elements

Heat straightening. Heat straightening, another method of repairing members, is used mainly to straighten members that have become distorted due to impact or overload. Generally, it is accomplished through the application of heat (by use of torches) and cold (by use of dry ice) on specific locations of the structural steel member, which induces it to straighten out. This is such a specialized method that maintenance personnel typically should not attempt to perform the process.

Cracking due to brittle fracture. This type of cracking occurs when a high stress or strain develops at a point where the material has lost its ductility. The high stress or strain can be due to one or more causes. Once the crack or cracks have been observed, it is important that they be arrested. Bolted splices have been used to provide increased capacity and a method of placing material in the crack path in the hope of stopping it. Another procedure is to weld strips of material to the fracture paths. However, neither of these procedures should be attempted until a structural analysis has been made to determine if, in fact, the cracking is due to a brittle failure.

Lamellar tearing. Lamellar tearing is simply the pulling apart of a hot rolled steel member in its thinnest dimension. The source of the problem is a welding-caused contraction in highly restrained connections. Lamellar tearing is a separation within the steel, caused by through-thickness strains induced by shrinkage of hot weld metal as it cools. It occurs mainly in corn and T-joints. It is more serious with thick steel members and with large cross-section welds.

To prevent such problems, the steel members being welded should be free to move closer together as the weld metal cools and shrinks. The American Institute of Steel Construction suggests that electrodes that have the lowest acceptable weld-metal yield strength be used. This helps to reduce the tendency for Lamellar tearing. This type of deterioration is often hard to detect because minute tears in the metal occur under weldments. Therefore, it is of extreme importance that all large welds be 100% X-rayed at the steel fabricator's plant and in the field (if in-place field welding is being done).

The repair of Lamellar tearing of structural members in existing buildings should be a collaborative effort between the facility's owner and the steel fabricator. The process often involves detailed reviews of the nondestructive testing results and involvement by utility structural engineers.

6.1.3 Repairing Wood/Timber Structural Members

6.1.3.1 General Repair Guidance

The majority of repairs of timber members are usually accomplished by replacing or reinforcing the timber. The method used, such as that listed here, depends on the type of forces the member carries and its function in the building.

- Replace compression members or splice a new section into the good portion.
- Splice tension members using side plates. It is very difficult to design a splice in a tension member. However, if it is done, check to ensure that it is, in fact, carrying the tensile load. Replacement is a more effective means of repairing a tensile member.
- Replace or splice bending members. Splicing would be done where the bending movement is zero, which is usually near a support. A structural analysis can be used to locate the point of zero movement.
- Replace rather than splice braces.
- Remove hardware that has corroded or disintegrated to the point of being ineffective and replace it with an oversized or a higher-strength connector.

Whether replacing or repairing, a structural analysis should be done to determine the extent of structural damage.

When the damage done by decay is extensive, replace the deteriorated member with timber having the same strength characteristics and size as the existing element. The decision regarding whether the deterioration is extensive enough to warrant replacement should be based on economics.

If the decision is made to replace the element, the following general items should be kept in mind when developing the repair procedure:

- Remove any live loads and dead loads imposed on the structural member.
- Provide any temporary supports needed to ensure that the repair procedures do not result in a premature failure of the member.
- Using applicable hand and power tools, remove all decayed material.
- Treat the damaged surface with a fungicide coating to help prevent any further deterioration.

6.1.3.2 Glue-Laminated Members

Glue-laminated members do not ordinarily have the same defects as solid wood because laminated members are kiln dried before gluing and are made up of small and selected pieces. In addition to making the same type of inspection as for solid wood members, periodically inspect glue-laminated components for delamination or separation between pieces of a member. Carefully examine minute cracking; cracks larger than 1/16 in. should be examined by a structural engineer.

6.2 Repair of Facility Finish Materials

6.2.1 Exterior Materials

6.2.1.1 Wood Exteriors

Where existing situations are satisfactory, replace damaged material with similar material. Cut back sufficient areas beyond the damaged part to obtain good joining and sound nailing. Tighten nails in existing material. Ensure that materials receiving the new nailed pieces of sections are sound. Cover replacement wood with treatment and/or paint, matching the original design. Remove warped, split, or curled shingles with a ripper and check for looseness and faulty caulking. It is usually more economical and satisfactory to replace damaged or deteriorated panels than to attempt patching them.

When existing siding does not meet the functional requirements of a building or structure, careful consideration should be given to re-siding over the existing material. The utility's engineering organization should be consulted for planning the job and preparing the plans and specifications.

6.2.1.2 Metal Exteriors

Protected metal surfaces. For small areas (under 10 $in.^2$) where metal core is exposed, the manufacturer's recoating compound should be used to ensure compatibility.

Type A and B materials. Coat the exposed metal, including a width of about 1 in. of the adjoining felt and bituminous-covered surfaces, with asphalt primer. Allow the primer to dry for at least 24 hours. Then apply bituminous plastic cement. Build up the plastic cement to form a continuous plane with adjoining surfaces. When the cement has been exposed to the weather for at least 24 hours, apply a coat of bituminous compound. Thin the compound to finishing consistency with a suitable solvent and apply it at the rate of about 1 gal to 125 ft^2. Overlap the adjoining area about 1 in.

Type C material. Follow the treatment recommended for Type A and B materials except that the final coat should be of an asphalt-base emulsion. While the coating is still tacky, cover it completely with 160-mesh mica topping.

For large areas (10 in.^{2} or more) of exposed metal core, the following process is recommended.

Type A and B materials. Prime the metal surfaces and about 1 in. of the adjoining area as recommended for small areas. Then apply a brush coat of bituminous compound, using about 1 gallon for each 75 ft^2. While the compound is still wet, apply 48- by 48-mesh unbleached muslin weighing 4 oz per linear yd, or a porous, tough mat of fiberglass reinforced with random continuous glass yarns and bonded with a resinous binder compatible with bituminous coatings. Before using the muslin, soak it in clean water until all sizing has been removed, and hang it up until it is damp dry. Apply the damp muslin or the fibrous glass at right angles to the corrugations, using material as wide as practicable and overlapping the edges about 3/4 in. Press the muslin or glass mat firmly and evenly into the bituminous compound. Provide a continuous pleat in the muslin, in the center of and parallel to each low corrugation of the projected metal roofing and siding. At the side or end laps, pleat the muslin or the glass at the edges of the overlapping sheets of protected metal and tuck the muslin or glass into the crevice between the sheets. Immediately after the muslin or glass is installed, apply a brush coat of the bituminous compound recommended for the first coat. Cover the muslin or glass completely. Allow this coat to dry for at least 24 hours. Then apply a final coat of the bituminous compound, at the rate of 1 gallon for each 75 ft^2 over the repaired area.

Type C material. Prime the metal surface, including a width of about 1 in. of the adjoining bituminous covering, as recommended for smaller areas. Then apply a brush coat of asphalt-base emulsion at the rate of 1 gallon for each 75 ft^2. While the emulsion is still wet, apply muslin or a fibrous glass mat as recommended for Type A and B materials. Immediately after the muslin or fibrous glass is installed, apply a finish coat of the asphalt emulsion, covering the muslin or fibrous glass completely. Allow the emulsion to dry for at least 24 hours. Then apply a final coat of the emulsion at the rate of 1 gallon for each 75 ft^2. While this coat is still tacky, apply an overcoat of 160-mesh mica topping.

Exposed felt. Apply a brush coat of bituminous compound over the exposed felt. If the felt is dry and bleached, apply the compound at the rate of about 1 gal to 100 ft^2. If the felt is only a few years old and is in good condition, apply the bituminous compound at the rate of about 1 gallon to 150 ft^2. Allow the coating to dry for at least 24 hours. Then apply a final coat of bituminous compound at the rate of about 1 gallon to 75 ft^2.

Rusted and loosened bolt and screw heads. Replace corrosion-weakened bolts and screws with new bolts or screws. If the old holes are too large for the new fasteners, drill new holes in an adjoining solid portion of the sheet. Use stainless steel sheet metal screws for fastening sheets to each other, and use stainless steel self-tapping screws to fasten sheets to structural steel. Clean the rust from old holes, cover them with muslin or fibrous glass patches, and recoat them as recommended for repairing large areas of exposed metal core.

Caulking side and end laps. If water is entering the building through the laps, caulking of the laps is usually necessary. Before caulking, however, be certain that all fasteners in the vicinity of the leads are tight. Remove all dirt and debris from the laps. Using a caulking gun, lay a continuous bead of plastic cement along the edge of the protected metal sheet. Then force the

cement into the lap with a putty knife or a small pointing trowel. After the cement has been worked into the lap, smooth off the exposed cement and remove any excess cement.

Painting. Recoat or paint protected metal if the existing coatings are dry and brittle. Recoating or painting extends the life of the protected metal for several years. Type C material cannot be painted or recoated unless the surface mica is removed or has disappeared. Follow the manufacturer's instructions for surface preparation, mixing, application, and inspection.

6.2.1.3 Masonry and Concrete Exteriors

Mortar repair. Weathering can cause spalling of mortar joints under the best of conditions, but poor mortar mixes are usually at fault when the face of masonry walls is marred by stains and efflorescence. Impure water that contains acids or other damaging matter and improper sand in the mortar mix not only cause stains through bleeding, but also allow wear in mortar joints in excess of that caused by normal weathering. Mortar repair can encompass any of the following procedures:

- Repointing
- Repair of cracks (in the wall)
- Repair of mortar joint cracks
- Repair of unit cracks (wide and/or large)
- Repair of unit cracks (fine and/or small)

Parapet repair. In most cases, about 20 ft of the parapet should be removed, beginning at the corners. A new section of parapet, doweled into the wall below, is then laid. A 1-in.-wide vertical expansion joint is provided at the juncture with the existing parapet. Provide through-wall metal flashing and a continuous seal of bituminous plastic cement at the bottom of and in the expansion joint.

6.2.1.4 Mineral-Surfaced Board Exteriors

Broken shingles and corrugated or flat sheets should be replaced promptly and secured by methods recommended by the manufacturer, using standard clips and fasteners wherever possible. For field repair involving the use of nails, bolts, or rivets, use the proper drilling tools and saws for appropriate cutting. Do not use fastening devices or common nails, bolts, and washers that are subject to weathering and corrosion. Where material is placed over wood sheeting, ensure that the nailing base is in sound condition before adding the new materials.

6.2.2 Interior Ceiling and Wall Materials

6.2.2.1 Plaster

The appropriate repair procedure depends on the type of plaster being repaired. The various types of plaster are similar in composition and application, but designed for specialized uses. The most common repair with plaster is the repair of structural, map, or shrinkage cracks. Generally, two coats of patching material are required to repair wide, structural cracks. The first coat can be a mixture of 1 part fibered gypsum plaster and 2 1/2 parts plastering sand, by volume, mixed with clean water. Material for the second coat can be either a neat gypsum plaster or a mixture of 1 part hydrated lime and 1/2 part calcined gypsum mixed with water to a suitable consistency. A small amount of casein glue can be added to these mixes to ensure easier application, because it tends to retard the setting time of the mix.

Holes are repaired using the same procedure as for structural cracks. Bulges can be repaired by creating a hole where the bulge appears, and then proceeding with the repair of the hole. Loose plaster should be removed from around the break, working well back in the surrounding area to a point where solid plaster (well keyed to the lath) is obtained. Repairs are made similarly to those for structural cracks.

6.2.2.2 Drywall

Joints in drywall construction that fail must be recemented and taped. Broken sections of interior wallboard are generally best corrected by replacement of an entire panel.

6.2.2.3 Ceramic Tile

Cracked and broken tile should be replaced promptly to protect the edges of adjacent tile and to maintain waterproofing and appearance. Timely point of displaced joint material and spalled areas in joints is necessary to keep tiles in place.

6.2.2.4 Acoustical Tile

In most cases, a broken piece of acoustical tile should be replaced instead of repaired. If repair is deemed necessary, use an acceptable gluing process consistent with the type of material the tile is made of and the manufacturer’s recommendations.

6.2.2.5 Wood

Minor repairs can be made to the wood as long as the appearance is not ruined. The repairs can include:

- Fill an indentation with a wood-base filler, then sand, and follow with painting or staining.
- Fill an indentation with a panel filler that matches the wood.

- Repair localized splitting or checking by covering the damage with a filler-type material, and follow with a protective sealer, stain, or paint.
- Refinish wood damaged by water staining or stain from substances such as atmospheric corrosion by using sandpaper or fine steel wool, and follow with refinishing, resealing, and buffing (as for wood floors).

If the extent of the damage is widespread or the appearance is marred by a localized repair, the wood member should be replaced. Remove the portion of the member that has been marred back to the supporting element of the member. Replace with a new member of the same grade, quality, and appearance along with needed finishing work such as filling, staining, or painting.

6.2.3 Floors

6.2.3.1 Resilient Floors

The biggest problem in patching a tile floor is obtaining new tiles or sheet material that matches the color and pattern of the existing flooring material. After a floor has become badly marred, scuffed, or pockmarked, there is little that can be done except to replace the floor or to grind it down below the indentation mark.

6.2.3.2 Masonry Floors

Ceramic tiles should be replaced with similar tiles as needed and grouted with the same product as used originally. Repair of concrete floors is described in Section 6.1 of this report. Terrazzo, granolithic, and magnesite floors can be repaired in accordance with the specifications for putting in the new original floor. Only floor specialists who are capable of this type of workmanship should be entrusted to repair these types of floors.

6.2.3.3 Metal Floors

Repair of metal floors is usually accomplished by replacement of plating (covering) or grating.

6.2.3.4 Seamless Floors

Repairs of extensive areas should be accomplished using the same method used when installing the original floor. For the repair of small areas, scrape the damaged area clean using a metallic scraper. Then apply plastic chips and paste. (In essence, a small section of the floor is rebuilt on the spot.) Smooth the patch and finish it off with a sealer.

6.2.3.5 Wood Floors

Wood floors should be inspected for loose nails, loose boards, raised ends, slivers, cracks, loose knots, raised nails, and damage from improper cleaning, condensation, and wood decay.

Procedures for repair of specific problems associated with wood floors can include the following:

- Secure loose wood boards or tiles.
- Replace wood strips/planks.
- Replace wood blocks/tiles.
- Resurface (sand, stain, varnish, seal, and polish) a wood floor surface.

6.2.3.6 Carpets

Extensive repair of carpeting is often uneconomical, particularly if reweaving is needed. As a general rule, repair work should be deferred when:

- More than 10% of the carpeting requires skilled repair work.
- The carpeting is approaching the end of its useful life.
- Areas with worn spots, holes, tears, and frayed edges can be covered by furniture or scatter rugs.
- The carpeting can be cut to useful dimensions for other applications.

Professional carpet installers perform the majority of carpet repairs. Some of the more common carpet repairs include the following:

- Replace tuft (furling).
- Repair frayed edges.
- Patch a hole in the carpet.
- Repair a rough seam.
- Repair a damaged seam.
- Restretch a loose or buckled carpet.

6.2.4 Roofs

The scope of roof repairs described in this section typically includes minor repairs to the roofing exterior materials and does not include replacement of the entire roofing system.

6.2.4.1 Built-Up Roofs

In general, for mineral surfaces, asphalt and asphalt-saturated felt should always be used in the maintenance of asphalt built-up roofs and coal-tar pitch and coal-tar saturated felt in the maintenance of coal-tar pitch built-up roofs. Asphalt and coal-tar pitch are not compatible; avoid contact between the two. In this section of guidance, the terms *bitumen* and *bituminous* are used

to indicate asphalt—when asphalt roof repair is described—and coal-tar pitch—when coal-tar pitch roofs are described—respectively.

Bare areas (small areas). For bare areas where the bituminous coating is exposed, first brush any loose gravel or slag from the bare areas. Then cover the bare area with hot bitumen poured on at a rate of about 70 lb per square, and embed fresh gravel or slag. Old gravel or slag can be reapplied when the dirt and dust have been screened from it. Do not attempt to apply hot bitumen over slag or graveled surface because it will not adhere. If felts are exposed and appear to be weathered, brush all dust and dirt from the exposed area, and in the case of asphalt roofs, apply one thin coat of asphalt primer. When the primer is dry, treat as described for bare areas with the coating exposed. Coal-tar pitch roofs are treated similarly, except that no primer is required before the coal-tar pitch is applied.

Weathering. When the bituminous coating is weathered severely over the entire roof area, remove the coating and mineral surfacing. Removal is best accomplished in cool weather. When large roof areas are involved, the use of mechanical equipment to remove the bituminous coating and surfacing material can prove to be more economical than removal by hand. However, the purchase of such mechanical equipment is usually not justified. Repair disintegrated felt, damaged areas, blisters, and buckles as described in the following paragraphs. Seep off loose material. Recoat with hot bitumen poured on at a rate of about 70 lb per square, and embed 400 lb of gravel or 300 lb of slag in the hot bitumen.

Felts exposed. For small areas where felts are exposed and partially disintegrated, scrape off all surfacing materials to at least 2 1/2 ft beyond the area of disintegrated felts. Remove disintegrated felt layers, and replace them with new 15-lb bituminous-saturated felts of approximately the same size, mopped in place with hot bitumen. Apply at least two additional layers of 15-lb saturated felt, mopped on with hot bitumen and extending at least 12 in. beyond the area covered by the replacement felts. Apply hot bitumen to the repaired area at a rate of 70 lb per square, and into it, while hot, embed fresh gravel or slag. Old gravel or slag can be reapplied if dirt and dust are screened from it.

Cracked roof membrane. Treat as described for disintegrated felts, except that it is usually necessary only to mop on at least two plies of 15-lb saturated felt, followed by heavy pouring of bitumen, with slag or gravel surfacing.

Large blisters or buckles. Blisters or buckles, although large, do not leak when intact. However, if they allow water to penetrate, they should be repaired. To treat, scrape off all surface material to a dry felt surface at least 2 1/2 ft beyond the edge of the blister or buckle. Make two cuts at right angles to each other extending 12 in. beyond the edge of the blister or buckle. Fold back the four corners of the membrane and allow to stand until thoroughly dry. When dry, apply a liberal mopping of hot bitumen, fold down the four corners of the membrane, and press them firmly into the hot bitumen to produce a flat area. Apply at least two additional layers of 15-lb saturated felt, mopped down with hot bitumen, and extend at least 18 in. beyond the edges of the cuts. Apply a pouring of hot bitumen at a rate of 70 lb per square, and while hot, embed gravel or slag.

When felts have been exposed and are disintegrated in numerous areas, no definite criteria can be established to determine whether the existing membrane should be repaired by adding plies of felt or the old membranes should be removed entirely and a new one applied.

Fishmouths or buckled open-end laps. Repair by scraping off all surfacing material to a distance of at least 12 in. beyond the affected area. Cut the fishmouths or buckled end lap and cement down the loose felts with hot bitumen. Apply at least two layers of 15-lb saturated felt, mopped on with hot bitumen and extending at least 8 in. beyond the end of the cut felt and 8 in. below the lap edge. Apply a heavy pouring of hot bitumen, and while hot, embed gravel or slag into the coating.

6.2.4.2 Asphalt Shingle Roofs

Asphalt shingles should be applied in accordance with current specifications for construction. For this type of repair, the consultation and/or use of a roofing contractor is recommended.

6.2.4.3 Asphalt Rolled Roofs

General repairs of asphalt rolled roofs can range from recoating to repair of large and small breaks, large areas, and leaky seams. To treat smooth-surfaced rolled roofing, remove all loose dirt and dust by sweeping, vacuuming, or air blasting. Apply asphalt emulsion, asphalt-based coating, or fatty acid pitched-based roof coating. The coating of asphalt primer should be omitted for all but the most severely weathered roofs.

Repairs of breaks, large areas, and leaky seams should be conducted in accordance with current construction specifications. For this type of roof repair, the consultation and/or use of a roofing contractor is recommended.

6.2.4.4 Asphalt Cement Roofs

Repair of asphalt cement roofs typically involves replacing broken shingles. Shingle replacement depends on the style with which the shingles have been applied: American, hexagonal, or Dutch. The consultation and/or use of a roofing contractor is recommended.

6.2.4.5 Metal Roofs

Copper roofing. For flat-seamed roofs, when broken soldered seams indicate inadequate provision for expansion and contraction, new expansion joints sufficient to provide a joint at intervals of not more than 10 ft in each direction should be installed. For batten and standing seam roofs, if soldered horizontal seams are broken, loose lock seams that permit movement of the sheet should be installed. Small holes in copper roofing can be repaired with a drop of solder. In soldering copper, scrape the metal with a sharp instrument or emery cloth until bright metal shows on any surface that is in contact with the solder. Then apply zinc chloride or resin as a flux, and tin the surface with a thin coating of solder. It is a poor practice to coat copper roofing,

flashing, and gutters with an asphaltic mastic coating for the repair of small holes and breaks. Larger breaks, not caused by inadequate provisions for expansion and contraction, can be repaired by soldering a piece of copper over the hole.

Tin roofing. For broken soldered seams, resolder in accordance with the instructions for soldering copper. For leaking formed seams, reform or caulk with a plastic caulking material. For small breaks, repair with a drop of solder, and for larger breaks, solder a piece of tin roofing over the break.

Galvanized steel roofing. Leaks at seams and fasteners in galvanized steel roofing can be repaired by caulking the seams, or in severe cases where caulking is impractical, by stripping the laps.

Aluminum roofing. Consultation and/or use of a roofing contractor is recommended for repairs of aluminum roofing systems.

Protected metal roofing. Consultation with the roofing system manufacturer and the use of a roofing contractor is recommended for repairs of protected metal roofing systems.

6.2.4.6 Slate Roofs

In replacing a broken slate, first remove all pieces and cut the nails with a ripper. Insert a new slate of the same color and size as the broken one, and nail it through the vertical joint of the next course above, driving the nail about 2 in. below the butt of the slate in the second course above the nail, and bend the strip slightly concave to hold it in place. The strip usually extends about 2 in. under the course and covers the nail and extends 2 in. below it.

6.2.4.7 Wood Shingle Roofs

Broken wood shingles can be removed by the methods recommended for removing broken slates, but at least four nails must be cut. After the broken shingle is removed, insert a new one of the same size, and nail it through the exposed butt, preferably with thin copper nails. Also nail the shingle immediately above through the exposed butt.

6.2.4.8 Single Membrane Roofs

Consultation with the single membrane roofing system manufacturer and the use of a roofing contractor is recommended for repairs of these specialized roofing systems.

6.2.5 Windows and Doors

Minor repairs of windows and doors is typically integral to the maintenance of these components and is described in Section 5 of this report. Major repairs to windows and doors should be accomplished in accordance with each manufacturer's recommendations. Consultation with the

manufacturer and the use of an installation contractor is recommended for major repairs of windows and doors.

6.2.6 Coatings for Exterior Surfaces

The repair of coatings systems that have severely degraded or deteriorated depends highly on each particular manufacturer's recommendations for surface preparation, inspection, mixing, application, and curing/drying. Therefore, the user of this report should consult the coatings manufacturer for further guidance, depending on the type of coating, substrate, and plant-specific application in which the coating is used.

6.3 Repair of Facility Systems

6.3.1 Water Distribution Systems

6.3.1.1 Fresh and Waste Water Plumbing Systems

Routine maintenance of plumbing systems typically involves regular inspection of the systems and their components as described in Section 4 of this report and minor repair of inoperable system components. In some cases, system repair can require the replacement of a given component in lieu of trying to repair it. Because of the many unique designs of components installed in fluid systems, repairs of any assembly or component within the plumbing system should be performed in strict accordance with each manufacturer's recommendations. Therefore, no further guidance is provided in this report.

6.3.1.2 Fire Protection Systems

Any repair of fire protection system components should be performed in accordance with NFPA standards and is not described in any detail in this report. Guidance regarding routine maintenance of fire protection system components is provided in EPRI report 1006756, *Fire Protection Equipment and Surveillance Optimization and Maintenance Guide* [4].

6.3.2 Heating, Ventilating, and Air Conditioning Systems

Routine maintenance of the varied components installed in HVAC systems typically involves regular inspection of the systems and their components, system rebalancing as needed, and replacement of inoperable system components/parts. Any repairs to HVAC system components should be done in strict accordance with each respective manufacturer's recommendations and by qualified and licensed personnel. Therefore, no further guidance is provided in this report.

6.3.3 Electrical Systems

For the purposes of this report, electrical systems include distribution systems, lighting systems, motors, batteries, transformers, and alarm/public address systems. These various systems are typically designed to accommodate replacement of worn or defective elements in lieu of trying to repair those elements. As noted in Section 5 of this report, routine maintenance of electrical systems typically involves regular inspection of the systems and their components and replacement of inoperable system components. Any repairs to major components should be done in strict accordance with the respective manufacturer's recommendations and by qualified and licensed personnel. Therefore, no further guidance is provided in this report.

6.3.4 Conveying Systems

For the purposes of this report, conveying systems include hydraulic elevators, traction elevators, and escalators. These various systems are typically designed to accommodate replacement of worn or defective elements in lieu of trying to repair those elements. As noted in Section 5 of this report, routine maintenance of conveying systems typically involves regular inspection of the systems and their components and replacement of inoperable system components. Any repairs to major components should be done in strict accordance with the respective manufacturer's recommendations and by qualified and licensed personnel. Therefore, no further guidance is provided in this report.

6.4 Repair of External Systems

6.4.1 Walks, Drives, Curbs, and Asphalt Surfaces

Repairs must be made as soon as possible after locating the defects. This is especially true with asphalt surfaces because, after deterioration begins, further deterioration progresses at a more rapid rate than for most materials due to the superimposed loadings and nature of the material. One important precaution taken with asphalt surfaces is the application of a sealer coat about six months after the surface has been constructed and once each year thereafter. Table 6-1 provides a summary of recommended maintenance repairs to address the types of deterioration seen in asphalt surfaces.

Table 6-1
Maintenance Repairs for Asphalt Surfaces [1]

Failure Mechanism/Deterioration	Maintenance Repair Procedure
Alligator cracks	Firm and level area: seal coat. Loose or spongy area: remove and patch.
Bleeding and softening	Refer to repair procedures published by the Asphalt Institute.
Chuckholes	Clean out chuckholes down to the base and patch.
Depressions	Remove the defective area down to the soil, recompact the soil, provide drainage if it is a problem, and patch.
Edge breaking	Provide lateral support by filling in other material. Follow by removing damaged area and patch.
Long cracks	Clean out crack (to 1-in. wide or more), fill with crack filler, and resurface.
Numerous wide cracks	Clean out crack (to 1-in. wide or more), fill with crack filler, and resurface.
Raveled surfaces	Clean surface and seal coat.
Softening	Clean and scrub well with strong detergent. If severe, remove area and patch.
Weathering of the surface	Clean surface and seal coat.

A general repair procedure for patching and sealing asphalt surfaces, using a commercially available cold-mix patching compound, is presented here. For a more complete description of the various types of asphalt pavement deterioration and applicable repair procedures, refer to *Asphalt in Pavement Maintenance* [7].

Equipment and materials typically required are as follows:

- Equipment
  - Shovel
  - Tamper
  - Stiff-bristle broom
  - Water hose
  - Squeegee
- Material
  - Asphalt
  - Patching material
  - Sealer compound
  - Blacktop sealer

The procedure follows these steps:

1. Dig out all loose material from the bottom of the hole.
2. If the hole is deep, place gravel over the bottom and tamp it firmly to provide a good foundation.
3. Fill the hole with a cold-mixed patching compound to within 1 in. of the top.
4. Tamp the compound firmly with a hand or mechanical tamper, depending on the size of the repair.
5. Pour additional cold mix into the hole until it is about 1/2 in. higher than the surrounding surface.
6. Give the repair a final tamping.
7. For small cracks or other voids, spread dry sand over the surface. Sweep the sand off the smooth surface without removing it from the voids and crevices.

Once all cracks and broken areas have been patched, the surface can be sealed. If possible, this should be done on a dry, sunny day, using the following process:

1. Sweep the surface clean and remove all greasy areas.
2. Wet down the entire surface, making sure any puddles are swept away.
3. Apply the blacktop sealer and ensure that it dries overnight before using it.
4. A second coat might be needed, but do not apply it until the first coat has dried overnight.

6.4.2 Runoff, Drainage, and Erosion Control Systems

In many cases, minor repairs of these systems and structures is integral to the routine maintenance performed on a regular basis, and therefore is described in Section 5 of this report. Major repairs of runoff, drainage, and erosion control systems and structures should be coordinated with appropriate civil and/or structural engineering personnel.

6.4.3 Fences

6.4.3.1 Patching

Small holes in wire fabric fencing can usually be patched. Fasten the patch on one side and stretch it across the hole, then fasten the other side, the top, and the bottom, using heavy tie wires twisted inside the fence. The cut ends of the wires of the patch are generally inside the fence to complete the job.

6.4.3.2 Replacing Chain-Link Fencing

Chain-link fencing is generally fastened to or through terminal posts by tension bars, approximately 3/16 x 3/4 in., threaded through the links, and clamped to the terminal posts. When a section of fencing is replaced, the intermediate posts on each side of the damaged section become terminal posts while the work is being done, and the tension bars should be used while the damaged section is being replaced. Use tie wires or install temporary braces to support these posts against the pull of the adjacent fencing when the damaged section is removed unless the remaining fence is adequately braced by the top rail. After removing the damaged section, cut off the proper length of fencing to span the gap, and fasten one end to one of the temporary terminal posts, using a tension bar and clamps. Stretch the new section across the gap and pull it tight, then secure the free end to the other temporary terminal post with a tension bar and clamp. Cut the excess material in a neat manner and remove the temporary tie wires and braces. Install the tension wire at the top of the new section or tie the top of the new section to the top rail to match the type of support used in the fence being repaired. Touch up the cut ends of steel wire with aluminum paint to prevent rusting.

6.4.4 Tanks

Repairs of aboveground or elevated storage tanks should be performed only when the tank is empty and clean. Repairs can include relining of the interior tank walls, replacement of piping or instrumentation, or repair of cracks or tears in the tank wall and structural supports.

Repairs of underground storage tanks are not feasible. Take care when removing underground storage tanks to ensure that there is no loss of content into the surrounding soil. In addition, take care to ensure that local, state, and federal environmental regulations are followed when removing or replacing underground storage tanks.

7
FACILITIES MAINTENANCE MANAGEMENT

This section provides guidance for individuals responsible for managing the maintenance activities associated with existing facilities and buildings. Whereas the primary focus of this report thus far has been understanding failure mechanisms and performing actual maintenance activities (that is, condition assessment, inspection, and repairs), this section describes facilities issues from a managerial perspective. Over the life of a structure, many issues arise that are most effectively addressed at a management level. The use of the structure, the expected life of the structure, and repair versus replacement analyses are examples of typical issues that arise during the life of a building, issues that oftentimes do not have easy answers. This section provides guidance to give managers a better appreciation of the many aspects of managing a facility, optimizing its usage, and ensuring the reliability of the structure for facilitating the processes it houses.

7.1 Repair, Replacement, and Deferral Analysis

The question of whether to repair, replace, or defer maintenance on a facility or a deteriorated building element is often a complicated one to answer. The issue is further complicated depending on whether the analysis is performed for an entire facility or simply a particular building element of an existing facility. In most cases, thorough economic cost study is the only effective way of attaining a quantified answer.



Key O&M Cost Point

As a general rule of thumb, if the repair costs 50% or less than the replacement cost, then repair should be considered. If the percentage is greater, then replacement is generally the best option.

This rule of thumb is generally effective if the facility can be put out of service during replacement construction. Of course, another option is to do nothing or defer the maintenance.

7.1.1 Factors Considered During Comprehensive Analysis

Figure 7-1 illustrates factors that should be considered when performing a comprehensive analysis. Some of the factors are easier to quantify than others; and in some cases, actual costs can be estimated. To quantify the results of the analysis, some factors can be weighted as to their relative importance in the calculation.

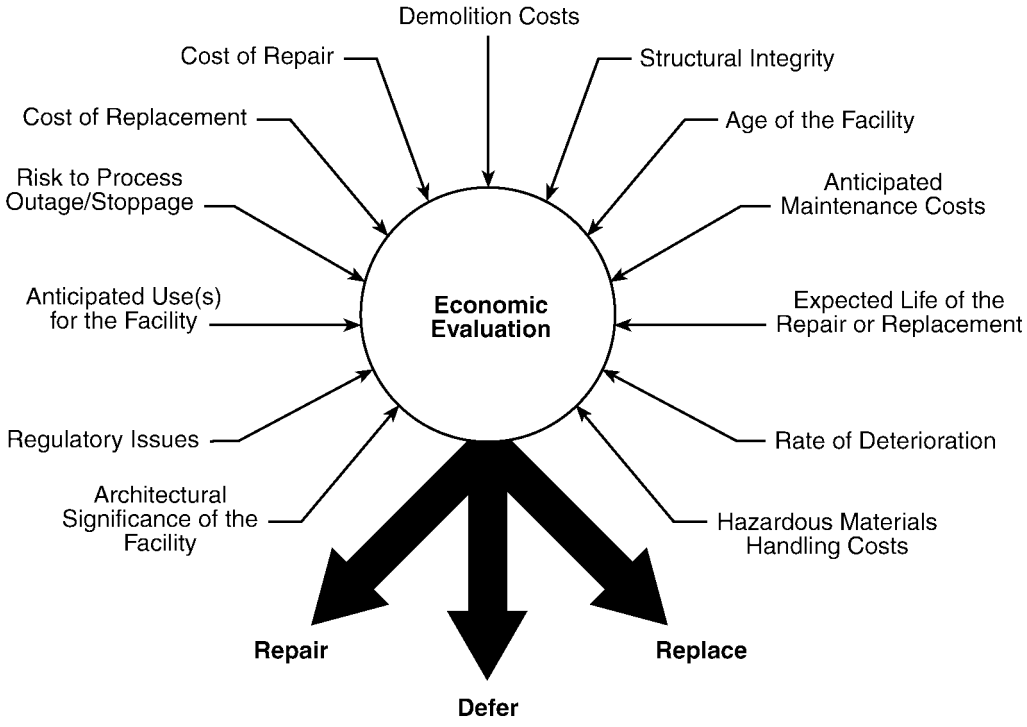


Figure 7-1
Factors Considered During the Decision-Making Process
(Courtesy of Sequoia Consulting Group, Inc.)

Because of the complexity of the analysis and the varying relevancy of each factor, this report does not attempt to provide a mathematical equation for performing such a calculation. Some of the factors are more qualitative in nature and as such tend to be more difficult to quantify in those cases where an economic cost study is desired.

Each of the factors illustrated in Figure 7-1 is described here in more detail. This list of factors is not all inclusive and is provided for illustrative purposes only.

In some cases, examples are provided to demonstrate how a particular factor can be evaluated and how it might be relevant in certain cases. These examples are likewise provided only for illustrative purposes and would not be deemed applicable in all cases encountered at facilities at a power-generating station or a U.S. DOE nuclear processing facility, nor are they considered to be all inclusive.

7.1.1.1 Quantifiable Factors for Economic Cost Study

Some factors are easier to quantify than others, and as such in some cases costs can be estimated for each course of action. Brief descriptions of the quantifiable factors and costs are the following:

- **Cost of the repair.** One of primary factors that should be considered is the cost of the repair. This cost is typically made up of the costs for materials, equipment, labor, and preparation needed to perform the repair. For the purposes of this report, this cost would not include

follow-on maintenance costs associated with maintaining the repaired building element(s) over the life of the facility.

- **Cost of replacement.** Another primary factor that should be considered is the cost of replacement. This can apply to either the entire facility or a particular building element under evaluation. Similar to estimating the cost of a repair, replacement costs should include the costs for materials, equipment, labor, and preparation needed to replace the existing facility or building element. Likewise, for the purposes of this report, this cost would not include follow-on maintenance costs associated with maintaining the replaced building element(s) over the life of the facility.
- **Anticipated maintenance costs.** When making the decision to replace or repair a particular building element, the manager should consider the anticipated maintenance costs associated with either action. Whether a building element is replaced or repaired, there are costs associated with maintaining it for some period of time. An estimation of projected maintenance costs should include the following components:
  - Maintenance equipment costs: special equipment and/or tools are often required to perform a repair or to replace a building element. The costs of using these items should be factored into the decision as to whether to replace the building element or repair it.
  - Labor costs: the labor costs associated with projected or anticipated maintenance are important to consider because they might constitute a significant component of the costs if the life expectancy of the facility or building element is high. Labor costs can be affected by the availability of maintenance personnel, whether special or unique skills are required, and/or whether the maintenance personnel are in house or contracted.
- **Demolition costs.** In many cases, there are significant demolition costs associated with a replacement that are not necessarily as important when performing a repair. Demolition costs should include costs associated with preparing the structure for the replacement, removal of the building elements that have been replaced, and disposal of the waste.

  Example: A facility has experienced some water damage from a roof leaking during heavy rainstorms. The leakage appears to be localized to about 4–5 separate locations on the roof. The facilities maintenance manager considers the demolition costs of replacing the entire roof, which include the removal of the old roofing materials (such as shingles, tar paper, and flashing), and repairing any damaged structural elements that are discovered after the removal of the old roof.
- **Hazardous materials handling costs.** In some cases, there are costs associated with handling certain hazardous materials—such as asbestos, lead paint, and hazardous chemicals—that should be factored into the overall cost of performing maintenance and/or repair on existing facilities. These costs can be so significant that the most economical option is to defer the maintenance or repair until the end of the service life of the facility.

7.1.1.2 Key Qualitative Factors in the Decision-Making Process

Three key qualitative factors that should be considered in the analysis are the structural integrity of the facility (now and in the future), the rate of deterioration, and the architectural significance of the facility and its outward appearance.

- **Structural integrity of the facility.** One of the key factors affecting the decision-making process is the structural integrity of the facility and the degree to which the deterioration has caused collateral damage to the structure. If the building element has not deteriorated to the point of causing structural damage to the facility, repair might be the most economical choice at this time. However, if the deterioration has caused structural damage and the structural damage must be repaired, then replacement of the building element might be feasible in order to minimize the chances of further deterioration, failed repairs, and/or more severe structural damage to the facility.

  The structural integrity of the facility should also be considered in the long term by considering the future impact of worsening conditions on the usage of the building, the uninterrupted processes within the structure, and the safety of the employees using the facility.

- **Rate of deterioration.** The rate of deterioration is another factor that should be considered when evaluating the cost benefits of either repairing or replacing a building element. The rate of deterioration primarily impacts the urgency with which the element needs to be addressed. For an element failing at a slow rate, the facilities maintenance manager is afforded additional time to decide on the course of action. In some cases, the rate of deterioration can be so slow that the best course of action is to defer any action until the building element's condition becomes more severe. Elements failing at a faster rate require more prompt action.

- **Architectural significance of the facility.** In some cases, the replacement of certain building elements might not be desirable, because there is a need to preserve the architectural integrity of the building in relation to other facilities on site or to maintain the aesthetic qualities of the structure (possibly from a historical perspective). If this is an issue, replacement of particular building elements with new ones might not be as desirable as repairing (or restoring) the existing building elements in order to preserve architectural integrity.

  Example: A training building that was designed and constructed to architecturally match other administrative buildings located in proximity to it now experiences problems with the windows located on the ground floor of the structure. Identical replacement windows are no longer available, and the replacements that would be comparably priced to the old ones are a different design and color. Because installation of the replacement would disrupt the architectural integrity of the surrounding buildings, the facilities maintenance manager decides to repair the existing windows.

7.1.1.3 Other Qualitative Factors for Consideration

Other qualitative factors that should be considered in the analysis are described here. The extent to which these factors are relevant vary but are presented here to stress the potential significance to the decision-making process.

- **Age of the facility.** The age of the facility should be factored in the evaluation for a number of reasons. First, the older the facility, the less likely it is that repairs are feasible. Conversely, the newer the facility, the less likely that it is beneficial to replace the entire structure and the more likely that it is to perform repairs of needed building elements. Second, older facilities can have several maintenance issues that need to be considered simultaneously. Therefore, the repair costs of these multiple issues should be considered together and not separately.

  For buildings and facilities that are approaching the end of their expected life, repair or replacement of building elements might not be economically feasible. In these cases, the best option might be to take no action and to simply use the facility until a new one is available.
- **Risk to process outage/stoppage.** The risks associated with inadvertently interrupting the process(es) housed in the facility should be considered from short- and long-term perspectives. In the short-term perspective, the manager should consider which action, repair or replacement, would present the least risk to interrupting the processes. In some cases, a repair can be performed without any disruption to the processes within a facility, whereas a replacement might require the facility to be evacuated or the process equipment shut down until the replacement is complete. When this is the case, the manager might also consider the cost of lost production necessitated by the replacement.

  Example: The carpeting in an existing facility used for administrative support functions at a nuclear power plant is worn to the point of it causing safety and tripping hazards for employees as well as being unsightly for new or contract employees reporting on site for outage-related work. Replacing the entire carpeted area would require the temporary displacement of the employees, their computers, and their office furniture, which would not be possible in the months leading up to the refueling outage. Repairing the carpet to eliminate the unsafe aspects to employees could be performed after hours causing only minimal disruption to work processes taking place during the first and second shifts. Once the outage is complete, a suitable time is scheduled to temporarily relocate employees while the carpeting is being replaced.

  In the long-term perspective, the manager should consider the effectiveness of the maintenance activity, the facility's or building element's susceptibility to failure, and the need for repeated repairs, all with respect to the risk imposed over time to inadvertently disrupting the processes within the facility.

  Example: A facility containing computer equipment and servers requires maintenance to address the water-tightness of the roof. The roof has been repaired several times to address the leaks, but with varied success. The risk of repeated repairs is the chance that a lead will short out or damage the electrical wiring for the computer equipment. Replacing the roof poses less of a risk to the long-term protection of the equipment because the new roof is less likely to leak if it is properly installed.

  In addition, in the long-term perspective, the manager should consider the risk that deferring repairs or maintenance will have on inadvertently interrupting work processes housed within the facility. In some cases, deferring the repair or maintenance can jeopardize the work

processes at some point in the future, and it might be significant enough to put employees at risk of personal injury.

- **Anticipated use(s) for the facility.** When deciding the best course of action, the manager should ascertain whether the facility can be used or has been considered for other uses in the future. Depending on how the facility will be used might impact whether it is more economical to repair or replace certain building elements.

  Example: An existing facility currently used for coatings application requires maintenance on the windows that have become difficult to open and keep water tight. The facilities maintenance manager learns that the coatings work will be relocated to a central facility operated by the utility in about 12 months, and the existing facility will be used as a warehouse, requiring only about a fifth of the windows that are currently installed in the building. In this case, replacing the windows now would most likely not be the best option, and repair would probably be most economical.

- **Expected life of the replacement or repair.** Another factor that should be considered is the expected life of the replaced or repaired building element. Regardless of what action is taken, the restored condition will not last forever. In time, the building element will have to be initially repaired, repeatedly repaired, or replaced again. The length of time until one of these follow-on activities varies depending on the maintenance decisions made now.

- **Regulatory issues.** Regulatory issues that might have arisen or new regulations that might have been enacted since the original construction of the facility should also be considered when deciding the optimum maintenance action to take.

  Example: An existing facility currently used for training plant operations personnel requires maintenance on asbestos insulation installed on a number of HVAC ducts and steam pipes. Current regulations restrict the use and handling of asbestos materials; these restrictions were not in effect when the facility systems were designed and installed. In this case, replacing the asbestos insulation would most likely not be the best option due to the significant costs associated with its handling, removal, and disposal. Instead, the repair of jacketing and containment devices to mitigate the consequences of asbestos particle release would probably be most economical.

7.2 Decision-Making Process

Figure 7-2 illustrates a generic process that can be used to perform the comprehensive analysis regarding repair, replacement, or deferral of maintenance activities. The structural integrity of the facility, the rate of deterioration, and the importance of the building's outward appearance are three key qualitative factors that should be considered. For simplicity, the other factors presented in Section 7.1 are collectively considered and might not be relevant to every situation encountered.

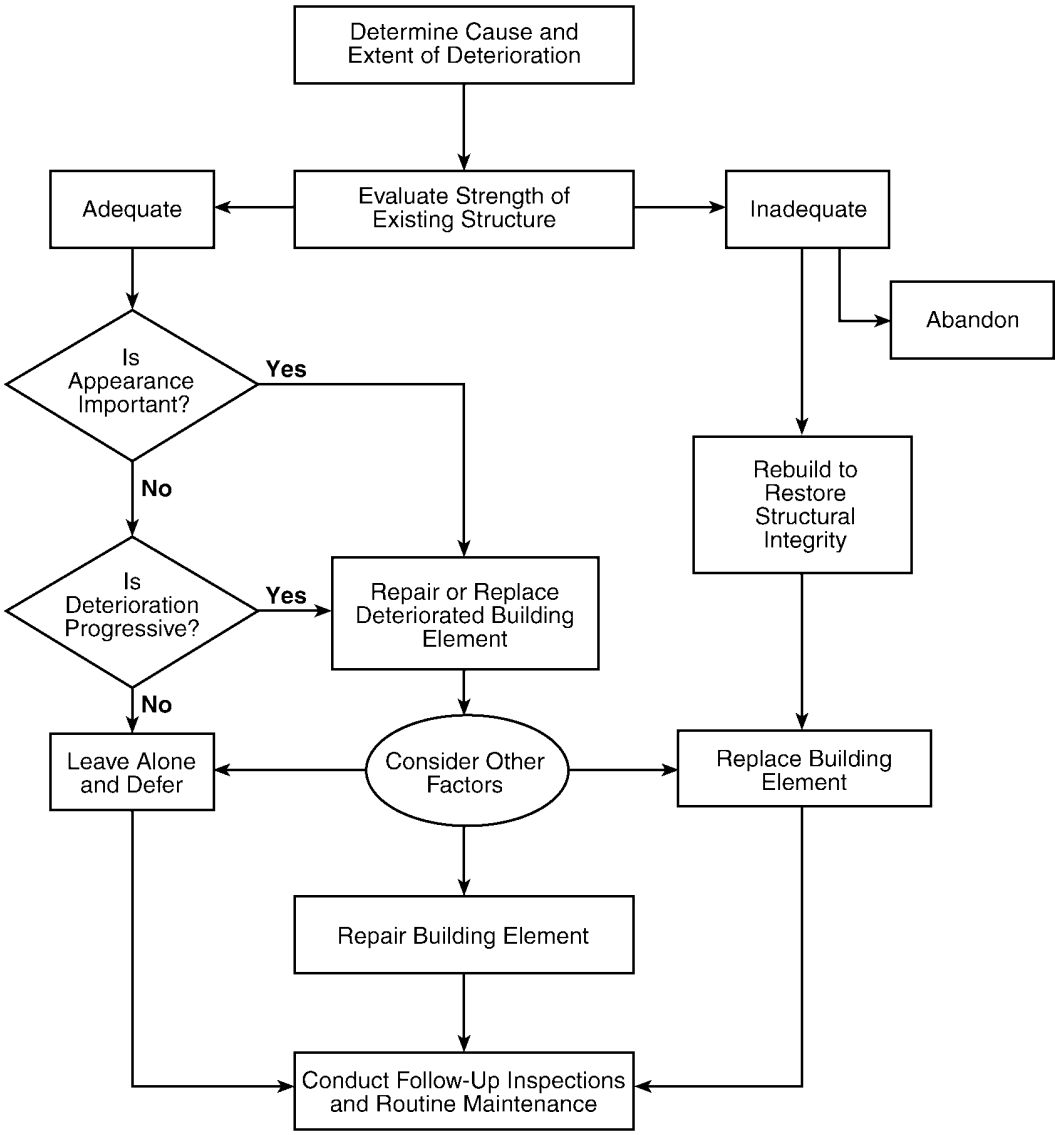


Figure 7-2
Process for Managing Facilities Maintenance Decisions (Based on Means)

7.2.1 Decision to Repair Deterioration

If the deterioration appears to have affected the material, component, or member to such an extent that it creates an unsafe condition, an engineer should be called to evaluate the strength of the existing member. Their recommendations usually fall into one of the following categories:

- Continued usage: no need for structural repair
- Restricted usage: no need for structural repair
- Usage prohibited: until structural repair has been made
- Abandon the member or structure: repair is not feasible or possible

Whether the strength of a member is adequate or inadequate is not the only criterion that should be considered when deciding on the need for a repair. Other criteria, such as appearance and economical feasibility, should also be considered.

If the anticipated decision is to repair the item, and the item has adequate strength, one of the following conclusions can be reached:

- If the present deterioration has produced an objectionable appearance, repair it.
- If appearance is not objectionable, determine if the deterioration is dormant or active:
  - If dormant, leave it alone.
  - If active, study the future effects of the repair. Will it cause the member or adjacent members to lose their strength?

    If so, repair now, taking these items into consideration. If not, consider the possibility of repair now or in the near future.

On the other hand, if repair is called for and the material has, or shortly will have, inadequate strength, one of the following conclusions must be reached:

- Repair or rebuild immediately.
- Abandon all or part of the system.
- Consider changing the use of the area or the item.

7.2.2 Repairing Deterioration

7.2.2.1 Selecting a Repair Procedure

If repair is needed, a procedure should be selected and implemented. Some of the things that should be considered when selecting a repair procedure are:

- Cost: initial cost, future maintenance, and investment value of deferred costs
- Time of repair
- Extent of repair
- Future effect of the repair
- Appearance
- Operations in the vicinity of the repair
- Possible strength changes of existing members due to the repair

Repairing for the incorrect cause is an incorrect repair procedure and can cause additional problems. Relative to the economics affecting the decision about making a repair, the user is referred to references on engineering economics.

7.2.2.2 Additional Repair Considerations

In selecting a repair procedure, the goal is to choose the least expensive method to do the job effectively. For any cause or causes, there can be a number of acceptable repair procedures. Follow a methodical process. The first step is to list the facts about the deterioration and its causes. Do not include assumptions or value judgments at this time, only the observed or known facts. Involve all persons who will be affected by the repair or who have been affected by the deterioration.

Second, based solely on the facts, list all of the repair procedures possible that would alleviate the deterioration. From the list of acceptable procedures, select one and implement it. Some repair procedures are easy to implement, such as when a worker is given the tools and equipment and is asked to make the repair. An example procedure is making a small, isolated repair when there is no threat of structural collapse, such as the repair of peeling paint.

However, when the repair job becomes of such magnitude as to require close and careful supervision, design calculations, and incorporating various crafts and equipment, a complete set of specifications and drawings should be prepared prior to making the repair. The drawings and specifications help to ensure that the repair is done effectively and efficiently, using workers and materials of high quality.



Key O&M Cost Point

It is often useful to know the expected lifetime of the component under consideration when deciding whether to replace or repair it.

Appendix B of this report provides tables that provide estimated design lives for various building components.

7.2.3 Deferring a Repair

It is often possible to defer a repair if the strength—now and in the near future—is adequate. If funds, personnel, and/or time are not immediately available, making a repair at a later date may be acceptable. If this is the case, the organization should set up an effective inspection program to check on the deterioration in question on a regular, frequent basis. Deferred action often results in a larger, more costly repair procedure. Many times one is apt to want to take so-called immediate quick steps to slow down the deterioration, such as the application of a preservative treatment on rotting wood. This type of action will only add to the ultimate cost of the repair.

7.2.4 Using Contractors and Outsourcing Repairs

Some of the repairs/replacements described in this section might need to be performed, or might best be performed, by outsourced licensed contractors. This decision depends primarily on the technical skills and expertise of the facilities maintenance organization, which vary from site to site. The decision to outsource contracted labor to accomplish common repairs and replacements of building elements (for example, roofs, windows, and concrete) can also depend on local or state licensing requirements, union practices, and local labor laws. The information in this report is for

guidance only. Users should select the most appropriate personnel to perform the repairs. In some cases, it is cost effective to outsource the job to an independent contractor.

7.2.5 Evaluating the Effectiveness of the Decision

After the repair or replacement has been made, a routine follow-up inspection must be made to determine if the selected procedure was effective or ineffective. If it was ineffective, another of the possible repair procedures selected in the earlier stage should be tried. A repair procedure can become a trial-and-error process, especially if there are many causes of the deterioration. After an effective repair has been made, frequent follow-up inspections of the repaired areas should be made.

7.3 Alternative Analysis Methods

For nuclear facilities managed by U.S. DOE, the facility condition index (FCI) is calculated to assist in making the decision regarding the course of action to take on a deteriorated facility or building element. The FCI equals the deferred maintenance costs divided by the replacement plant value (RPV). Both the deferred maintenance costs and the RPV are calculated in terms of dollars. A commonly used industry benchmark for the FCI at national laboratories is 5%, which U.S. DOE uses as a determination about whether to tear down or repair an aged facility.

By comparing the projected or deferred maintenance and repair costs against the RPV, an aged facility can also be rated/graded into condition categories. The condition descriptions used in facility condition assessments are defined per U.S. DOE guidance as follows:

- **Excellent.** Performs to original specifications as measured using nonstandard tests; easily restorable to "like-new" condition; only minimal routine maintenance required at a cost of <2% of RPV.
- **Good.** Performs to original specifications as measured using historical data and nonstandard tests; routine maintenance or minor repair required at a cost of <5% of RPV.
- **Adequate.** Performance meets requirements; some corrective and preventive maintenance required at a cost of <10% of RPV.
- **Fair.** Performance fails to meet code or functional requirement in some cases; failure(s) are inconvenient; extensive corrective maintenance and repair are required at a cost of <25% of RPV.
- **Poor.** Consistent substandard performance; failures are disruptive and costly; fails most code and functional requirements; requires constant attention, renovation, or replacement. Repairs are required at a cost of <60% of RPV.
- **Fail.** Nonoperational or significantly substandard performance. Replacement required because repair cost is >60% of replacement cost.

U.S. DOE also uses an asset condition index (ACI), which is calculated as ACI = 1 - FCI.

7.4 Other Facilities Maintenance Management Issues

7.4.1 Long-Term Costs of Facilities

Figure 7-3 illustrates that the total cost of a facility should be estimated by considering the design, construction, and ongoing maintenance costs that are incurred over the useful life of the structure. As a rule of thumb, the design and engineering costs tend to be approximately 10% of the construction costs, including the costs of material, equipment, and labor. Maintenance costs vary significantly depending on the expected life of the facility, the inherent design and quality of the original building elements, and the frequency at which the maintenance is actually performed.

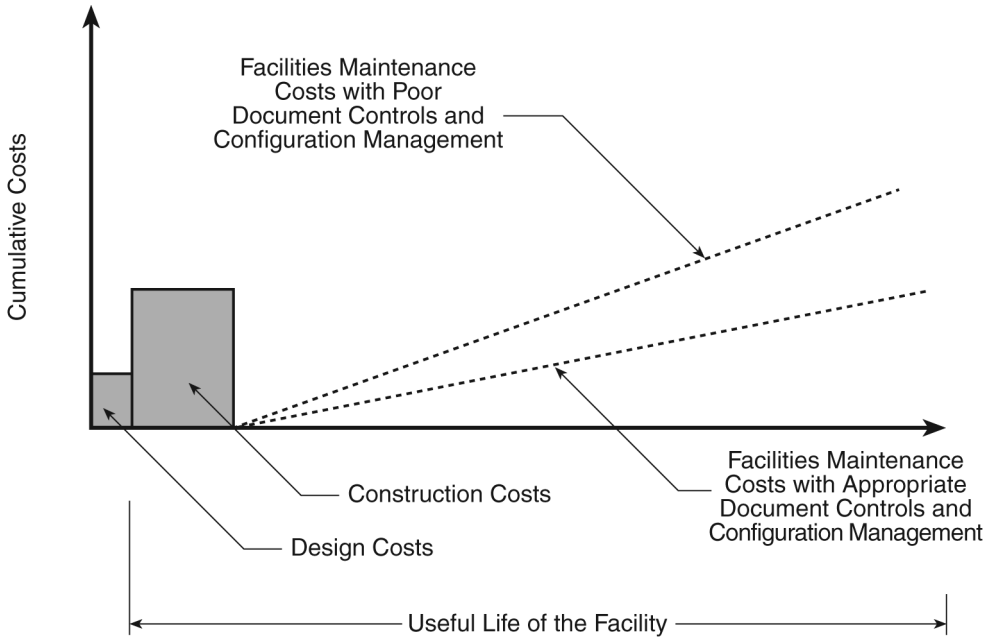


Figure 7-3
Long-Term Costs of Facilities
(Courtesy of Sequoia Consulting Group, Inc.)

7.4.2 Accessibility to Design Information and Configuration Management

Research conducted and lessons learned during the development of this report suggest that the most successful and effective facilities maintenance programs have one common attribute: the accessibility to current, accurate technical information regarding the as-built facility elements and components. As shown in Figure 1-1, the bulk of the technical information that should form the basis for any facilities maintenance program is the information provided by each product manufacturer. This product-specific technical information forms the baseline from which a program can build and initial condition assessments can commence.

An effective program should also have ready access to design/construction drawings of each facility, as well as the technical design/procurement specifications used. Together, these three types of technical information should be retained, be accessible, and be kept updated as physical changes are made. Figure 7-3 illustrates how appropriate document controls and configuration management can reduce the costs of ongoing maintenance over the useful life of a facility.

8
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8.4 Industry and Trade Organizations

Air-Conditioning and Refrigeration Institute (ARI). ARI is the national trade association representing manufacturers of more than 90 percent of North American produced central air conditioning and commercial refrigeration equipment. ARI traces its history back to 1903 when it started as the Ice Machine Builders of the United States. ARI was formed in 1953 through a merger of two related trade associations. Since that time, several other related trade associations have merged into ARI, making it the strong association that it is today. Over the past 45 years, ARI has emerged as the major voice for the air conditioning and refrigeration industry. For more information, visit the association's web site at www.ari.org.

Air Movement and Control Association (AMCA). The Air Movement and Control Association International, Inc. is a not-for-profit international association of the world's manufacturers of related air system equipment—primarily, but not limited to: fans, louvers, dampers, air curtains, airflow measurement stations, acoustic attenuators, and other air system components for the industrial, commercial, and residential markets. AMCA International, backed by almost 80 years of standards development, is the world's leading authority in the development of the science and art of engineering as relates to air movement and air control devices. AMCA International publishes and distributes standards, references, and application manuals for specifiers, engineers, and others with an interest in air systems to use in the selection, evaluation, and troubleshooting of air system components. Many of AMCA International's standards are accepted as American National Standards. For more information, visit the association's web site at www.amca.org.

American Architectural Manufacturers Association (AAMA). The AAMA is the source of performance standards, product certification, and educational programs for the fenestration industry. For more information, visit the association's web site at www.aamanet.org.

American Association of Textile Colorists and Chemists (AATCC). The AATCC is the world's largest technical and scientific society devoted to the advancement of textile chemistry. The AATCC has more than 5000 individual and 270 corporate members in the United States and in 65 countries. Since its inception in 1921, the AATCC has been dedicated to three objectives:

- Education: to promote increase of knowledge of the application of dyes and chemicals in the textile industry
- Research: to encourage in any practical way research work on chemical processes and materials of importance to the textile industry
- Communication: to establish for the members channels by which the interchange of professional knowledge among them may be increased

AATCC accomplishes these objectives through several activities: publications including but not limited to the monthly magazine, *AATCC Review,* and the annual *AATCC Technical Manual,* workshops and symposia, the annual International Conference and Exhibition, and member participation in research and technology committees. AATCC is also actively involved in developing ISO standards that pertain to the textile testing field. For more information, visit the association's web site at www.aatcc.org.

American Concrete Institute (ACI). Founded in 1904, ACI is a technical and educational society dedicated to improving the design, construction, maintenance, and repair of concrete structures. ACI publishes various technical bulletins and standards and provides numerous technical seminars and training courses. For more information, visit the institute's web site at www.aci-int.org.

American Hardboard Association (AHA). The AHA is a national trade organization and represents manufacturers of hardboard products used for exterior siding, interior wall paneling, household and commercial furniture, and industrial and commercial products. Hardboard is made from wood chips converted to fibers and permanently bonded under heat and pressure into a panel. The wood fibers are combined with natural and synthetic binders and other additives that improve certain properties. AHA serves as a central clearinghouse on industry and technical information for trade professionals, government agencies, and the general public. The association publishes brochures, pamphlets, and videos. AHA is concerned about the environment and it promotes educational and promotion programs. With the help of independent researchers, AHA conducts timely research activities relating to hardboard use and performance, improve industry standards and specifications, and work to update building codes. For more information, visit the association's web site at www.ahardbd.org.

American Institute of Steel Construction (AISC). AISC, headquartered in Chicago, is a not-for-profit technical institute and trade association established in 1921 to serve the structural steel design community and construction industry in the United States. AISC's mission is to make structural steel the material of choice by being the leader in structural-steel-related technical and market-building activities including specification and code development, research, education, technical assistance, quality certification, standardization, and market development. AISC has a tradition of more than 80 years of service to the steel construction industry providing timely and reliable information. For more information, visit the institute's web site at www.aisc.org.

American Institute of Timber Construction (AITC). The AITC is the national technical trade association of the structural glued laminated (glulam) timber industry. AITC represents a majority of the glued laminated timber manufacturers in the United States in addition to a number of installers, suppliers, sales representatives, engineers, architects, designers, and researchers. Since 1952, the AITC has had one name and one focus: structural glued laminated timber. Using the professional talents and extensive experience of its membership base, AITC developed, sponsored, and continues to maintain the American National Standard for Structural Glued Laminated Timber, ANSI/AITC A190.1. The recognition of AITC as the authority in the laminated timber industry is the direct result of the collaborative efforts of its members in the development and maintenance of today's industry design and product standards, the establishment of the benchmark industry quality assurance/inspection/grademark program, and laminated timber research. For more information, visit the institute's web site at www.aitc-glulam.org.

American Iron and Steel Institute (AISI). For over a century, North American steel producers have left their day-to-day rivalries behind to work as partners and members of the AISI in furthering its mission to promote steel as the material of choice and to enhance the competitiveness of the North American steel industry and its member companies. AISI's overall mission centers around common goals and a clear vision for the future:

- To provide high-quality, value-added products to a wide array of customers
- To lead the world in innovation and technology in the production of steel
- To produce steel in a safe and environmentally friendly manner
- To increase the market for North American Steel in both traditional and innovative applications

AISI is composed of producer member companies, including integrated, electric furnace, and reconstituted mills; associate member companies, which are suppliers to or customers of the industry; and affiliate member organizations, which are downstream steel producers of products such as cold rolled strip, pipe and tube, and coated sheet. For more information, visit the institute's web site at www.steel.org.

American National Standards Institute (ANSI). The ANSI is a private, nonprofit organization (501(c)3) that administers and coordinates the U.S. voluntary standardization and conformity assessment system. The ANSI's mission is to enhance both the global competitiveness of U.S. business and the U.S. quality of life by promoting and facilitating voluntary consensus standards and conformity assessment systems and safeguarding their integrity. For more information, visit the institute's web site at www.ansi.org.

American Plywood Association (APA). APA is a nonprofit trade association that has grown and evolved with the engineered wood industry. APA was founded in 1933 as the Douglas Fir Plywood Association, and was later recognized as the American Plywood Association. In 1994, APA changed its name to APA – The Engineered Wood Association to better reflect the range of products manufactured by APA members and the international scope of the Association. Those products now include plywood, oriented strand board, glued laminated timber (glulam), composite panels, wood I-joists, and laminated veneer lumber. APA is a leading source of information about engineered wood products for a wide range of applications. For more information, visit the association's web site at www.apawood.org.

American Society of Heating, Refrigeration and Air Conditioning Engineers (ASHRAE). ASHRAE will advance the arts and sciences of heating, ventilation, air conditioning, refrigeration, and related human factors to serve the evolving needs of the public and ASHRAE members. Membership is open to any person associated with heating, ventilation, air conditioning, or refrigeration through such disciplines as indoor air quality and energy conservation, for example. For more information, visit the association's web site at www.ashrae.org.

American Society of Mechanical Engineers (ASME). Founded in 1880 as the American Society of Mechanical Engineers, today ASME International is a nonprofit educational and

technical organization serving a worldwide membership of 125,000. ASME conducts one of the world's largest technical publishing operations, holds some 30 technical conferences and 200 professional development courses each year, and sets many industrial and manufacturing standards. The work of the society is performed by its member-elected Board of Governors and through its five councils, 44 boards and hundreds of committees in 13 regions throughout the world. There are a combined 400 sections and student sections serving ASME's worldwide membership. For more information, visit the association's web site at www.asme.org.

American Society for Testing and Materials (ASTM). ASTM International is one of the largest voluntary standards development organizations in the world, a trusted source for technical standards for materials, products, systems, and services. Known for their high technical quality and market relevancy, ASTM International standards have an important role in the information infrastructure that guides design, manufacturing, and trade in the global economy. For more information, visit the society's web site at www.astm.org.

American Wood Council (AWC). The AWC is the wood products division of the American Forest & Paper Association. AWC's mission is to increase the use of wood by ensuring the broad regulatory acceptance of wood products, developing design tools and guidelines for wood construction, and influencing the development of public policies affecting the use of wood products. AWC provides wood design and construction information to assist engineers and architects, develops structural and fire performance data on a wide range of traditional and engineered wood products, and engages in long-term research. For more information, visit the council's web site at www.awc.org.

American Wood-Preservers' Association (AWPA). The AWPA is a nonprofit organization that is responsible for promulgating voluntary wood preservation standards. AWPA standards are developed by its technical committees in an open, consensus-based process that involves individuals from all facets of wood preservation: producers of preservatives and preservative components; producers of treated and untreated wood products; end users of treated wood; engineers, architects, and building code officials; and government entities, academia, and other groups with a general interest in wood preservation. AWPA's standards are universally specified for wood preservation in the United States and are recognized worldwide. For more information, visit the association's web site at www.awpa.com.

Asphalt Institute. The Asphalt Institute is a U.S.-based association of international petroleum asphalt producers, manufacturers, and affiliated businesses. For more information, visit the institute's web site at http://www.asphaltinstitute.org.

Association for Facilities Engineering (AFE). AFE provides education, certification, technical information, and other relevant resources for plant and facility engineering, operations, and maintenance professionals worldwide. For more information, visit the association's web site at www.afe.org.

Brick Industry Association (BIA). Formerly Brick Institute of America, the organization's web site contains a directory of manufacturers and distributors searchable by state and product; technical FAQs for commercial/institutional, landscape, and residential use of brick; project

photo gallery; overview of code issues; wall cost comparisons; links to CAD resources; downloadable *Technical Notes on Brick Construction* and *Flexible Brick Paving Guide*; and a catalog of technical literature for sale online. BIA also offers online training courses. For more information, visit the association's web site at www.brickinfo.org.

Building Officials and Code Administrators International (BOCA). Founded in 1915, BOCA is a nonprofit membership association, with more than 16,000 members who span the building community, from code enforcement officials to materials manufacturers. BOCA is dedicated to preserving the public health, safety, and welfare in the built environment through the effective, efficient use and enforcement of Model Codes. BOCA provides a unique opportunity for any individual to join and derive the benefits of membership. Members are professionals who are directly or indirectly engaged in the construction and regulatory process. BOCA, ICBO, and SBCCI formally consolidated into a single, 50,000-member organization: the International Code Council (ICC). ICC provides world-class service to members and customers and it remains dedicated to public safety through the development of building safety and fire prevention codes. For more information, visit the council's web site at www.iccsafe.org.

Carpet and Rug Institute (CRI). CRI is the national trade association representing the carpet and rug industry. Headquartered in Dalton, Georgia, CRI's membership consists of manufacturers representing 94% of all carpet produced in the United States and suppliers of raw materials and services to the industry. There is continued coordination with other segments of the industry, such as distributors, retailers, and installers. The wide range of assembled information provides a focal point for issue discussion and a voice for the industry. The overall fields of interest are technical services, member services, governmental and consumer affairs, and public relations. CRI membership and staff are intensely involved in facilitating cooperative solutions to all industry challenges. CRI is a source of extensive carpet information for consumers, writers, interior designers, specifiers, facility managers, architects, builders, building owners and managers, installation contractors, and retailers. For more information, visit the institute's web site at www.carpet-rug.com.

Concrete Reinforcing Steel Institute (CRSI). CRSI is one of America's oldest trade associations. Since 1924, the CRSI has fostered the continued growth of reinforced concrete construction to its present multi-billion dollar status. CRSI's main objective has always been to increase the use of reinforced concrete in the construction industry. To meet this objective, CRSI supports an extensive marketing and promotion effort, as well as research and engineering support for the safe and proper use of materials in reinforced concrete construction. CRSI's technical staff has developed many publications and computer programs for use by designers, contractors, and others. The CRSI professional staff is nationally recognized for its skills, experience, and continuing work on specifications, building codes, and engineering practices that affect the construction industry. For more information, visit the institute's web site at www.crsi.org.

Door and Hardware Institute (DHI). DHI represents the architectural openings industry. With ancestry dating back to 1934, DHI has more than 5000 members in the United States, Canada, and abroad. Membership consists of individuals and consultants involved in the architectural openings industry, representing distributors, manufacturers, and sales representatives/agency

firms, as well as architects, specifiers, and contractors who rely on such professionals. For more information, visit the association's web site at www.dhi.org.

Energy Facility Contractors Group (EFCOG). The EFCOG promotes excellence in all aspects of the operation, management, and integration of DOE facilities in a safe, environmentally sound, efficient, and cost-effective manner through the ongoing exchange of information on lessons learned. For more information, visit the group's web site at http://www.efcog.org.

Exterior Insulation Manufacturers Association (EIMA). Founded in 1981, the exterior insulation and finish systems (EIFS) Industry Members Association (EIMA) is a national nonprofit technical trade association with more than 400 leading manufacturers, suppliers, distributors, and applicators involved in the EIFS industry. EIMA's mission is the advancement and growth of the EIFS industry through developing consensus technical, training, installation, and design standards for use by architects, designers, code bodies, and other technical associations. For more information, visit the association's web site at www.eima.com.

Flat Glass Marketing Association (FGMA). The Glass Association of North America (GANA) is the product of a 1994 consolidation of the Flat Glass Marketing, Glass Tempering, and Laminators Safety Glass associations. Its members are the major glass and metal manufacturers, glass and metal distributors/installers, and fabricators of tempered, laminated, and insulating glass. The building envelope contractors, distribution, laminating, mirror, and tempering each have a division within GANA. GANA produces a wide variety of technical documents and manuals, including the *GANA Glazing Manual*, *Sealant Manual*, *Engineering Standards Manual*, *Laminated Glass Design Guide*, *Fabrication, Erection and Glazing Hours Manual* and the *Fully Tempered Heavy Glass Door and Entrance Systems Design Guide*. For more information, visit the association's web site at www.glasswebsite.com

Gypsum Association (GA). GA is a not-for-profit trade association established in 1930. To be eligible for membership, a firm or individual must manufacture gypsum board. GA is located in Washington, D.C. It represents manufacturers of gypsum board in the United States and Canada and provides technical information and assistance to the construction industry and code enforcement community regarding gypsum board. For more information, visit the association's web site at www.gypsum.org.

Illuminating Engineering Society of North America (IESNA). IESNA is the recognized technical authority on illumination. For over 90 years, its objective has been to communicate information on all aspects of good lighting practice to its members, to the lighting community, and to consumers through a variety of programs, publications, and services. The strength of the IESNA is its diversified membership: engineers, architects, designers, educators, students, contractors, distributors, utility personnel, manufacturers, and scientists, all contributing to the mission of the IESNA: to advance knowledge and disseminate information for the improvement of the lighted environment to the benefit of society. The IESNA is a forum for the exchange of ideas and information and a vehicle for its members' professional development and recognition. Through its technical committees, with hundreds of qualified members from the lighting and user communities, the IESNA correlates research, investigations, and discussions to guide lighting experts and laypersons via consensus-based lighting recommendations. IESNA publishes nearly

100 varied publications including recommended practices on a variety of applications, design guides, technical memoranda, and publications on energy management and lighting measurement. The society, in addition, works cooperatively with related organizations on a variety of programs and in the production of jointly published documents and standards. In addition, the Society publishes *Lighting Design + Application (LD+A)* and the *Journal of the Illuminating Engineering Society (JIES)*. LD+A is a popular application-oriented monthly magazine. For more information, visit the society's web site at www.iesna.org.

Institute of Electrical and Electronics Engineers (IEEE). IEEE is a nonprofit, technical professional association of more than 380,000 individual members in 150 countries. Through its members, the IEEE is a leading authority in technical areas ranging from computer engineering, biomedical technology, and telecommunications, to electric power, aerospace, and consumer electronics, among others. Through its technical publishing, conferences, and consensus-based standards activities, the IEEE produces 30 percent of the world's published literature in electrical engineering, computers, and control technology, annually holds more than 300 major conferences and has nearly 900 active standards with 700 under development. For more information, visit the institute's web site at www.ieee.org.

International Facility Management Association (IFMA). IFMA is the Houston, Texas-based professional association for facility management with approximately 17,300 members in 127 chapters, 14 councils and 1 special interest group, covering 55 countries. IFMA was established in 1980 as a not-for-profit incorporated association dedicated to promoting excellence in the management of facilities. Globally, IFMA spots trends, conducts research, provides educational programs, and assists corporate and organizational facility managers in developing strategies to manage human, facility, and real estate resources. The combined purchasing power of IFMA's North American members is $81 billion (US$) annually. The organization offers networking opportunities through its regional chapters and councils structure, provides certification and educational programs, conducts research, spots trends, and assists facility managers in developing skills and strategies to manage the human, structural, and real estate assets of an organization. For more information, visit the association's web site at www.ifma.org.

International Maintenance Institute (IMI). The IMI was originally chartered as a nonprofit corporation in the State of Connecticut. The philosophy of the organization is to professionalize the maintenance function by helping maintenance managers to work smarter through the exchange of ideas and education. The IMI is a goal-driven organization made up of decision-making maintenance leaders as well as related sales and service professionals, all dedicated to keeping a nation's infrastructure operating smoothly. For more information, visit the institute's web site at http://www.imionline.org/.

Maintenance and Reliability Center (MRC). The MRC, headquartered at the University of Tennessee, is a premier institution for education, research, development, information exchange, and application of maintenance and reliability engineering. Maintenance and reliability engineering focuses on the use of management systems, analysis techniques, and advanced predictive and preventive technologies to identify, manage, and eliminate failures that lead to losses in system function. For more information, visit the center's web site at http://www.engr.utk.edu/mrc/.

National Association of Architectural Metal Manufacturers (NAAMM). NAAMM is the Chicago-based trade association representing manufacturers of a wide range of metal products used chiefly in commercial and industrial building construction. These products include metal stairs and railings, flagpoles, expanded metal, hollow metal doors and frames, steel and aluminum bar grating, and metal lathing and furring. Established in 1938, NAAMM currently has four operating divisions, with member firms producing specific products. NAAMM divisions enjoy considerable latitude in planning and conducting projects and programs. However, the underlying focus of each division is the same and follows the association's overall goals of:

- Developing, maintaining, publishing, and distributing technical information on metal products for building construction (includes specifications, manuals, and other information for building design professionals)
- Promoting the use of NAAMM technical resources, NAAMM member firms, and their products
- Providing a forum for the exchange of management and technical information among the members

For more information, visit the association's web site at www.naamm.org.

National Association of Garage Door Manufacturers (NAGDM). NAGDM, the first U.S. association devoted to garage door manufacturers, was established in 1968. In 1996, the Door and Access Systems Manufacturer's Association International (DASMA) was formed as the result of the consolidation of two of the industry's largest manufacturer associations: the Door Operator & Remote Controls Manufacturers Association (DORCMA) and the National Association of Garage Door Manufacturers (NAGDM). For more information, visit the association's web site at www.dasma.com.

National Association of Plumbing/Heating/Cooling Contractors (NAPHCC). NAPHCC has been an advocate for plumbing, heating, and cooling contractors since 1883. As the oldest trade organization in the construction industry, approximately 3700 members nationwide put their faith in the association's efforts to lobby local, state, and federal government, provide forums for networking and educational programs, and deliver the highest quality of products and services. NAPHCC's mission statement is the guiding principle of the association: "The Plumbing-Heating-Cooling Contractors-National Association is dedicated to the promotion, advancement, education and training of the industry for the protection of the environment, and the health, safety and comfort of society." For more information, visit the association's web site at www.phccweb.org.

National Fire Protection Association (NFPA). NFPA has been a worldwide leader in providing fire, electrical, and life safety to the public since 1896. The mission of the international nonprofit NFPA is to reduce the worldwide burden of fire and other hazards on the quality of life by providing and advocating scientifically based consensus codes and standards, research, training, and education. NFPA membership totals more than 75,000 individuals from around the world and more than 80 national trade and professional organizations. For more information, visit the association's web site at www.nfpa.org.

National Forest Products Association (NFPA). NFPA's lineage dates back to 1902, when regional associations, led by the Southern Lumber Manufacturers Association and the Mississippi Valley Lumbermen's Association, founded the National Lumber Manufacturers Association. It operated under this name until 1965, when, reflecting the increasingly integrated character of major forest industry firms, it took on the NFPA identification. However, NFPA remained a federation of associations until 1975, when a bylaw revision made it possible for individual companies to join directly. Until 1993, the forest products industry was represented by two organizations, the National Forest Products Association (NFPA) and the American Paper Institute (API), each independent institutions with some common membership. NFPA and API represented distinct sectors of the industry, with the former being the agent for the forest and building products industries while the latter represented pulp, paper, and paperboard manufacturers. Today both organizations are part of the American Forest and Paper Association (AF&PA). For more information, visit the association's web site at www.afandpa.org.

National Hardwood Lumber Association (NHLA). NHLA is a nonprofit trade association composed of more than 1800 members who produce, sell, and use hardwood lumber, or provide services to the hardwood industry. NHLA was founded in 1898 to establish a uniform system of grading rules for the measurement and inspection of hardwood lumber. While continuing to function as the keeper of these rules, NHLA now provides many additional services to its members and the construction industry in general. For more information, visit the association's web site at www.natlhardwood.org.

National Terrazzo & Mosaic Association, Inc. (NTMA). NTMA is a full-service nonprofit trade association headquartered in northern Virginia. The association establishes national standards for all terrazzo floor and wall systems and provides complete specifications, color plates, and general information to architects and designers at no cost. Membership in NTMA is limited to terrazzo contractors who meet rigid proficiency standards and participate in continuing educational seminars conducted annually by the association. For more information, visit the association's web site at www.ntma.org.

National Wood Flooring Association (NOFMA). The Wood Flooring Manufacturers Association was originally known as the National Oak Flooring Manufacturers Association. Since 1909, the principal function of NOFMA has been to formulate and administer industry standards on wood flooring. Establishing grading rules for flooring is a major part of these standards. For over a half century, NOFMA has been the voice of authority in the wood flooring industry, extending even to U.S. government agencies. In 1966, the Department of Commerce, National Bureau of Standards, FHA, and VA withdrew Product Standard CS56-60, Strip Oak Flooring, and accepted the NOFMA Official Flooring Grading Rules as the standard for the industry. Currently, only U.S. manufacturers of wood flooring are eligible to be NOFMA members. NOFMA member products' consistent quality sets its flooring apart from other manufacturers due to proprietary milling specifications and tolerances. As an industry source for technical information on wood flooring, NOFMA produces educational literature on the proper installation and finishing of wood flooring, along with numerous *Tip Sheets* to help solve potential problems that may occur. NOFMA offers two major five-day installation, sanding, and finishing schools each year and has initiated Wood Flooring Inspector Certification courses to be held several times a year. For more information, visit the association's web site at www.nofma.org.

National Wood Windows and Door Association (NWWDA). NWWDA provides a wide variety of tools to assist builders and other specifiers in decision making regarding wood windows and doors. Foremost among these specifying aids are the association's standards, published and updated periodically, to aid in the proper specification of a wide variety of products. A second major contribution is a complete range of NWWDA test methods. The association also makes available a wide variety of informational literature. Included, for example, are guides to installation of exterior wood swinging doors and fire-rated wood doors. Informational videos include a 15-minute guide and workbook outlining proper installation techniques for wood windows and doors, and a 16-minute explanation on wood door and hardware compatibility. Also available is the *Specifier's Guide to Wood Windows and Doors,* which contains a compendium of NWWDA standards and information literature. For more information, visit the association's web site at www.nwwda.org.

NASA Facilities Engineering Division, Planning & Real Estate Management Team. The mission of NASA's Facilities Engineering Division, Planning & Real Estate Management Team is to provide a global agency perspective of constructed physical resources. This perspective enables and enhances support of NASA Strategic Enterprises and Centers by other Code JX teams in the areas of strategic planning, requirements assessment, and facility data systems. Their long-term strategy is to develop, maintain, and continuously improve constructed resource information generated by NASA field centers in compatible relational database formats. This information base is used to conduct analyses and studies that contribute accurate and brief composite information that help form the basis for corporate decisions by NASA's top management and Strategic Enterprise Units. For more information, visit the division's web site at http://www.hq.nasa.gov/office/codej/codejx/codejx.html.

Plant and Facilities Maintenance Association (PFMA). PFMA is a nonprofit organization born to foster an exchange of information among maintenance professionals and provide technical information on emerging trends in plant and facility operations. A goal of the PFMA is to provide premier resource training, education, and other professional development skills that contribute to the ongoing success of a member's career or occupation. Founded in 2001, the PFMA membership has a keen understanding of what it takes to be a success in the plant and facilities fields. For more information, visit the association's web site at www.pfmainc.com.

Plumbing & Drainage Institute (PDI). PDI is an association of manufacturers of engineered plumbing products in a business area commonly referred to by the mechanical side of the construction industry as "the drain business." PDI members and licensees make products such as floor drains, roof drains, sanitary floor drains, cleanouts, water hammer arresters, swimming pool drains, backwater valves, grease interceptors, fixture supports, and other drainage specialties. The objective of PDI is to promote the advancement of engineered plumbing products through publicity, public relations, research, and standardization of product requirements. In addition, PDI prepares, edits, and publishes standards relating to plumbing products, and provides certified testing, rating, and installation procedures for grease interceptors and water hammer arresters. For more information, visit the institute's web site at www.pdionline.org.

Portland Cement Association (PCA). Since its founding in 1916, PCA has had the same mission: "Improve and expand the uses of Portland cement and concrete." Where cement and concrete are concerned, so is the PCA: in manufacturing, in raising the quality of construction, in improving our product and its uses, and in contributing to a better environment. In practice, this mandate means well-rounded programs of market development, education, research, technical services, and government affairs on behalf of PCA members: cement companies in the United States and Canada. For more information, visit the association's web site at www.cement.org.

Precast/Prestressed Concrete Institute (PCI). PCI is a unique organization of producers, suppliers, and professionals dedicated to fostering greater understanding of the design and use of precast and prestressed concrete. It also encourages and recognizes excellence in the manufacture and use of these materials. Our professional members guide the institute's efforts in product innovation, new technology adaptation, design methods development, training, and quality assurance. Since its inception in 1954, PCI has been a dynamic force in the steady growth and the current position of this expanding industry. PCI is composed of more than 1400 professionals: engineers, architects, producers, and associate members striving to improve the quality, economy, and innovation of the construction industry by establishing new levels of design and engineering in precast applications. For more information, visit the institute's web site at www.pci.org.

Sheet Metal & Air Conditioning Contractors National Association (SMACNA). SMACNA is an international association of union contractors who perform work in industrial, commercial, institutional, and residential markets. They specialize in heating, ventilating, and air conditioning; architectural sheet metal; industrial sheet metal; kitchen equipment; specialty stainless steel work; manufacturing; siding and decking; testing and balancing; service; and energy management and maintenance. The voluntary technical standards and manuals developed by SMACNA contractors have found worldwide acceptance by the construction community and foreign government agencies. ANSI has accredited SMACNA as a standards-setting organization. SMACNA does not seek to enforce its standards or provide accreditation for compliance. SMACNA standards and manuals address all facets of the sheet metal industry, from duct construction and installation to air pollution control, from energy recovery to roofing. SMACNA's Technical Resources Department fields several thousand technical questions annually from architects, engineers, manufacturers, and government personnel. For more information, visit the association's web site at www.smacna.org.

Single-Ply Roofing Institute (SPRI). SPRI is made up of numerous sheet membrane and component suppliers, consultants, testing and research agencies, and product distributors to the commercial roofing industry. The institute publishes technical bulletins and standards. For more information, visit the institute's web site at www.spri.org.

Society for Maintenance & Reliability Professionals (SMRP). SMRP is an independent, nonprofit society by and for practitioners in the Maintenance & Reliability Profession. The society is nearly 2000 members strong with global penetration, and is growing each day as individuals and companies representing a variety of manufacturing industries learn more and join. For more information, visit the society's web site at http://www.smrp.org/index.html.

Society for Protective Coatings (SSPC). SSPC was founded in 1950 as the Steel Structures Painting Council, a nonprofit professional society concerned with the use of coatings to protect industrial steel structures. In 1997, the name of the association was changed to The Society for Protective Coatings to better reflect the changing nature of coatings technology and the ever-expanding types of construction materials. SSPC is the only nonprofit association that is focused on the protection and preservation of concrete, steel, and other industrial and marine structures and surfaces through the use of high-performance industrial coatings. SSPC is the leading source of information on surface preparation, coating selection, coating application, environmental regulations, and health and safety issues that affect the protective coatings industry. The association's many industry-specific products and services include standards development, technical publications (books, videotapes, CDs), training courses, company and individual certification programs, publications, conferences, and an expanding range of online resources. For more information, visit the society's web site at www.sspc.org.

Steel Door Institute (SDI). SDI is a voluntary, unincorporated, nonprofit business association formed to promote the use of steel doors and frames in the construction industry. Since 1954, SDI has published technical documents and ANSI Standards to aid architects and specifiers in the selection, care, and use of steel doors and frames. For more information, visit the institute's web site at www.steeldoor.org.

Truss Plate Institute (TPI). TPI members are truss plate manufacturers engaged in the manufacture, sale, and distribution of metal connector plates for the wood truss industry. Members provide integrated component design and management software, featuring 2-D and 3-D CAD layout routines, lumber cutting and truss jigging solutions, and connection specifications. In addition, nearly all plate manufacturers offer professional engineering services and plant layout support. All plate manufacturers manufacture and/or broker an extensive array of truss/component assembly machinery, such as material handling equipment, computerized component cutting saws, hydraulic and roller presses, assembly tables with optional automatic jigging, and flat and vertical truss stacking systems. For more information, visit the institute's web site at www.tpinst.org.

Underwriters Laboratories, Inc. (UL). UL is an independent, not-for-profit product-safety testing and certification organization. UL has tested products for public safety for more than a century. Since their founding in 1894, UL has held the undisputed reputation as a leader in product-safety testing and certification within the United States. Building on a household name in the United States, UL is becoming one of the most recognized, reputable, conformity assessment providers in the world. Today, UL services extend to helping companies achieve global acceptance, whether for an electrical device, a programmable system, or an organization's quality process. For more information, visit the UL web site at www.ul.com.

U.S. DOE Condition Assessment Surveys (CAS). CASs are used by architects, engineers, and facility managers to gather facility condition assessment information. These data consist of architectural, civil, structural, electrical, and mechanical systems and components that are a part of the inspected asset or system. The program is deficiency based for collecting data on repair and replacement needs. Information is recorded on checklists preformatted to individual site needs, allowing for comments on unusual conditions to be documented on site. Data are recorded

in a database, where they can be reviewed, costed, and reported on using different scenarios. Costing and system deficiency data can be interfaced with the DOE Facility Information Management System (FIMS) database for department-wide distribution. For more information regarding CAS, visit their web site at http://cas.hr.doe.gov/.

A
KEY PROGRAMMATIC ELEMENTS

A.1 Facility Identification and Categorization

A.1.1 Functional Type of Categorization

The range and scope of structures, systems, and components (SSCs) that are integral to the facilities maintenance program vary from site to site. At nuclear generating facilities, extensive regulatory guidance has been provided to assist each licensee in identifying those SSCs that must be controlled (that is, designed, procured, installed, maintained, and operated) under an appropriate nuclear quality assurance program. Typically, those SSCs are not part of the facilities maintenance program. U.S. DOE nuclear facilities have—through regulation and site-specific commitments—similarly identified those SSCs that are "mission essential" and appropriately included those in some type of formal facilities maintenance program. At many fossil generating facilities, separate maintenance processes and organizations are designated to address maintenance of SSCs directly associated with the generation of electricity, as opposed to structures and facilities not directly associated with power generation.



Key Human Performance Point

It is incumbent upon each facility maintenance manager to understand the boundaries of responsibility regarding the routine maintenance of SSCs at each particular site.

There can be cases where the building is maintained by the facilities maintenance manager, and the equipment inside of the structure is maintained by another organization. There can also be cases where within a given building, the plumbing and lighting is the responsibility of the facilities maintenance manager, but piping and electrical components associated with the system (enclosed by the building) are maintained by some other organization.

A.1.2 Distinguishing Real Property

Another approach for categorizing SSCs is to distinguish between real property and process equipment. Although the guidelines for accomplishing this can vary somewhat, in general, real property consists of those assets that are permanent to the site and those that house the equipment used in producing a given product or providing a given service. In the most general terms, maintenance of real property is typically the responsibility of the facilities maintenance manager, whereas maintenance of the process equipment is typically the responsibility of the operations and maintenance organization.

A.2 Types and Prioritization of Maintenance Activities

A.2.1 Introduction

Past and current maintenance practices in both the private and government sectors would indicate that maintenance consists of the actions associated with equipment repair after it is broken. The dictionary defines *maintenance* as the work of keeping something in proper condition; upkeep. This would indicate that maintenance should be actions taken to prevent a device or component from failing or to repair normal equipment degradation experienced with the operation of the device to keep it in proper working order. Unfortunately, data obtained in many studies over the past decade indicate that most private and government facilities do not expend the necessary resources to maintain equipment in proper working order. Rather, they wait for equipment failure to occur and then take whatever actions are necessary to repair or replace the equipment. All equipment has associated with it some predefined life expectancy or operational life. For example, equipment may be designed to operate at full design load for 5000 hours and may be designed to go through 15,000 start and stop cycles. The design life of most equipment requires periodic maintenance. Belts need adjustment, alignment needs to be maintained, proper lubrication on rotating equipment is required, and so on. In some cases, certain components—for example, a wheel bearing on a motor vehicle—need replacement to ensure that the main piece of equipment (in this case, a car) lasts for its design life.

Any time maintenance activities are not performed as intended by the equipment's designer, the operating life of the equipment is shortened. Over the last 30 years, different approaches to how maintenance can be performed to ensure that equipment reaches or exceeds its design life have been developed in the United States. In addition to waiting for a piece of equipment to fail (reactive maintenance), preventive maintenance, predictive maintenance, and reliability-centered maintenance can be used.

A.2.2 Reactive Maintenance

Reactive maintenance is basically the "run it till it breaks" maintenance mode and is often referred to as corrective maintenance. No actions or efforts are taken to maintain the equipment as the designer originally intended to ensure that design life is reached. Studies as recent as the winter of 2000 indicate that this is still the predominant mode of maintenance in the United States. However, this report does not support this type of approach, and as such, focuses more on preventive and corrective techniques that enable the user to reach or extend the life of the building element or system component.

A.2.3 Preventive Maintenance

Preventive maintenance can be defined as actions performed on a time- or machine-run-based schedule that detect, preclude, or mitigate degradation of a component or system with the aim of sustaining or extending its useful life through controlling degradation to an acceptable level. By simply expending the necessary resources to conduct maintenance activities intended by the

equipment designer, equipment life is extended and its reliability is increased. In addition to an increase in reliability, dollars are saved over that of a program that only uses reactive maintenance. Studies indicate that this savings can amount to as much as an average of 12 to 18%.

Depending on the facilities' current maintenance practices, present equipment reliability, and facility downtime, there is little doubt that many facilities that rely only on reactive maintenance could save much more than 18% by instituting a proper preventive maintenance program. While preventive maintenance is not the optimum maintenance program, it has several advantages over that of a purely reactive program. By performing the preventive maintenance as the equipment designer envisioned, the life of the equipment can be extended closer to design. Preventive maintenance (such as lubrication and filter change) generally runs the equipment more efficiently and results in savings. While preventive maintenance is not expected to prevent equipment catastrophic failures, the number of failures can be decreased. Minimizing failures translates into maintenance and capital cost savings.

A.2.4 Predictive Maintenance

Predictive maintenance can be defined as measurements that detect the onset of a degradation mechanism, thereby allowing casual stressors to be eliminated or controlled prior to any significant deterioration in the component's physical state. Results indicate current and future functional capability. Basically, predictive maintenance differs from preventive maintenance by basing maintenance need on the actual condition of the machine rather than on some preset schedule. Preventive maintenance is time-based. Activities such as changing lubricant are based on time, such as calendar time or equipment run time. For example, most people change the oil in their vehicles every 3000 to 5000 miles traveled. This is basing the oil change needs on equipment run time. No concern is given to the actual condition and performance capability of the oil. It is changed because it is time. This methodology would be analogous to a preventive maintenance task.

If, on the other hand, the operator of the car discounted the vehicle run time and had the oil analyzed at some periodicity to determine its actual condition and lubrication properties, he or she might be able to extend the oil change until the vehicle had traveled 10,000 miles. This is the fundamental difference between predictive maintenance and preventive maintenance, whereby predictive maintenance is used to define needed maintenance tasks based on quantified material/equipment condition. The advantages of predictive maintenance are many. A well-orchestrated predictive maintenance program will all but eliminate catastrophic equipment failures. Maintenance activities can be scheduled to minimize or delete overtime cost. Inventory can be minimized and parts ordered as required, well ahead of time to support the downstream maintenance needs. The operation of the equipment can be optimized, saving energy cost and increasing plant reliability. Depending on a facility's reliance on reactive maintenance and material condition, it could easily realize savings exceeding 30 to 40%.

A.2.5 Reliability-Centered Maintenance

Reliability-Centered Maintenance Magazine provides the following definition of *reliability-centered maintenance* (RCM): "a process used to determine the maintenance requirements of any physical asset in its operating context." Basically, RCM methodology deals with some key issues not dealt with by other maintenance programs. It recognizes that not all equipment in a facility is of equal importance to either the process or facility safety. It recognizes that equipment design and operation differs and that different equipment has a higher probability to undergo failures from different degradation mechanisms than others. It also approaches the structuring of a maintenance program recognizing that a facility does not have unlimited financial and personnel resources and that the use of both must be prioritized and optimized. RCM is a systematic approach to evaluate a facility's equipment and resources to best mate the two and result in a high degree of facility reliability and cost effectiveness. RCM is highly reliant on predictive maintenance but also recognizes that maintenance activities on equipment that is inexpensive and unimportant to facility reliability might best be left to a reactive maintenance approach.

A.2.6 Deferred Maintenance

Deferred maintenance can be defined as maintenance that was not performed when it should have been or was scheduled to be, and which, therefore, is put off or delayed for a future period. Maintenance activities can be deferred for a number of reasons, some being more desirable than others. In many cases, maintenance is deferred simply due to a lack of resources, either financial or personnel, that are necessary to perform the activities when originally scheduled. Once the maintenance has been deferred, the organization ultimately responsible for maintaining the building element, facility, or system component is required to begin to develop a plan for catching up.

B
ESTIMATED DESIGN LIFE

This appendix provides tables of data that suggest estimated design lives for various building components. These values should be considered in addition to those estimates provided by the specific manufacturer of each particular building component. Actual service conditions affect the life expectancy of many of the components listed.

B.1 Foundations

Item Description	Replacement Life (Years)
Raft concrete slab foundation	Life of plant
Concrete grade beams	Life of plant
Cast-in-place concrete footings	Life of plant
Cast-in-place concrete foundation walls	75
Precast concrete foundation walls	75
Masonry foundation walls	50
Concrete block foundation walls	50
Stone foundation walls	45
Wood pile foundations, treated	50
Wood pile foundations, untreated	30
Precast concrete piles, square	75
Prestressed concrete piles	75
Cast-in-place concrete piles	75
Steel pipe piles, concrete filled	75
Steel pipe piles, nonfilled	75
Steel “H” piles	75
Wood with cast-in-place concrete composite piles	Life of plant
Wood with precast concrete composite piles	Life of plant
Foundation dampproofing	50
Foundation waterproofing	50
Excavation backfill	50

B.2 Substructures

B.2.1 Slabs on Grade

Item Description	Replacement Life (Years)
Standard 4-in. slab on grade	50
Standard 5-in. slab on grade	50
Structural 4-in. slab on grade	50
Structural 5-in. slab on grade	50
Concrete steps on grade	60

B.2.2 Columns

Item Description	Replacement Life (Years) Per DOE CAS
Wood columns, treated	50
Wood columns, untreated	30
Precast concrete columns	75
Prestressed concrete columns	75
Cast-in-place concrete columns	75
Steel pipe columns, concrete filled	75
Steel pipe columns, nonfilled	75
Steel “H” columns	75

B.3 Superstructures

B.3.1 Floor Slabs and Decks

Item Description	Replacement Life (Years)
Structural wood framing (includes sheathing, joists, and beams)	40
Corrugated metal deck with lightweight concrete topping	50
Corrugated metal deck only	30
Precast concrete (hollow core) roof slab	50
Poured-in-place gypsum concrete over form boards	40

B.3.2 Stairs

Item Description	Replacement Life (Years)
Metal-edged gypsum plank	40
Cement fiber planks	40
Precast concrete	50
Steel pan type, filled with concrete	40
Steel tread and riser	40
Prefabricated steel form filled with concrete	50
Steel frame, precast concrete treads and risers	40

B.3.3 Structural Frame

Item Description	Replacement Life (Years)
Steel structural frame (includes columns, beams, girders, trusses, spandrels, bracing, and fireproofing)	75
Reinforced concrete structural frame (includes columns, beams, and miscellaneous frame elements)	75
Precast concrete structural frame (includes columns, beams, and miscellaneous frame elements)	75
Wood structural frame (includes posts, girts, plates, studs, girders, and built-up beams)	50
Metal joist structural frame (includes metal joists and accessories)	75

B.3.4 Interior Structural Walls

Item Description	Replacement Life (Years)
Interior concrete block load-bearing walls	60
Interior brick load-bearing walls	75
Interior concrete load-bearing walls	75
Interior wood load-bearing walls	50

B.3.5 Floor Slabs and Decks

Item Description	Replacement Life (Years)
Reinforced concrete floor slabs (includes slab and beams)	50
Post-tensioned concrete floor slabs	50
Precast prestressed concrete floor slabs (can include planks, concrete, tees, floor channels, and structural concrete topping)	50
Noncellular open metal decking with structural concrete topping	50
Cellular metal decking with structural concrete topping	50

Estimated Design Life

B.4 Exterior Closures

Item Description	Replacement Life (Years)
Masonry veneer: 4-in. brick and 4-in. block, insulation, and vapor barrier	75
Precast concrete, veneer insulation, and vapor barrier	75
Stucco on metal studs, insulation, and vapor barrier	35
Stone veneer, block backup insulation, and vapor barrier	75
Aluminum panel, insulation, and vapor barrier	50
Metal panel, insulation, and vapor barrier	40
Cast-in-place 8-in. concrete wall, insulation, and vapor barrier	Life of plant
Concrete block (standard) 8-in., insulation, and vapor barrier	Life of plant
Split-face concrete block 8-in. wall, insulation, and vapor barrier	Life of plant
Plywood siding, Texture 1-11 with wood studs, insulation, and vapor barrier	30
Cedar siding, rough-sawn with wood studs, insulation, and vapor barrier	40
Redwood siding, board, and batten, insulation, and vapor barrier	40
Screen louvers, galvanized steel	15
Screen louvers, copper	25
Storm proof louvers, galvanized steel	15
Storm proof louvers, copper	25
Air grills, galvanized steel	15
Glass screen and metal frame	15
Preformed metal screen and metal frame	15
Fabric screen and metal frame	15
Cast-in-place concrete	75
Precast concrete	75
Brick masonry	75
Concrete unit masonry	60
Stone	75
Wood	30
Metal panels	40
Glass panes	40
Exterior gypsum board including metal hangers	12
Cement asbestos including metal hangers	16
Metal panels including metal hangers	40
Fixed glazing, frame, hardware	40
Operable glazing, frame, hardware	35
Single glazing, fixed frame, hardware	40
Double glazing, fixed frame, hardware	40
Reflective single glazing, fixed frame, hardware	40
Tinted single glazing, fixed frame, hardware	40
Aluminum spandrel panel	50
Stainless steel panel	50
Porcelain enamel panel	50
Weathering steel panel	50
Opaque colored-glass panel	40

Item Description	Replacement Life (Years)
Ceramic tile facing or panel	50
Stone facing or panel	75
Hollow metal door, frame, hardware	40
Solid-core wood door	40
Overhead metal service door, frame, hardware	30
Rolling metal service door, frame, hardware	30
Telescoping metal service door, frame, hardware	25
Revolving door, frame, hardware	25
Automatic sliding door, mechanism, frame, hardware (2 horsepower)	15
Aluminum panel, framing, insulation	50
Hollow metal panel, framing	40

B.5 Roofing

Item Description	Replacement Life (Years)
Asphalt and gravel built-up membrane roofing, 4-ply 15-lb felt	20
Prepared roll roofing, 15-lb felt	12
Single-ply/insulated roof material asphalt shingle (IRMAS)	
Inverted insulated roof member	20
Butyl rubber sheet roofing, self flashing	20
Neoprene sheet roofing	30
Hypalon sheet roofing	30
Metal roof system	
Copper roofing, flat, standing, or batten seam	50
Galvanized steel sheet metal	30
Coated foam membrane	15
Shingles	
Asphalt, fiberglass, and wood	30
Slate, cement	50
Tiles: metal, clay, and concrete	40
Roof drainage systems	
Gutters and downspouts	20
Scuppers, drains	20
Roof specialties	
Roof hatches, painted steel	24
Roof hatches, galvanized	40
Roof hatches, stainless	40
Relief valves	40
Skylights: single and double glazed	40

B.6 Interior Finishes and Construction

B.6.1 Walls

Item Description	Replacement Life (Years)
Brick partitions, exposed	75
Concrete block partitions, lightweight, exposed	60
Structural clay facing tile partitions, exposed	60
Drywall partitions, metal or wood studs	25
Lath and plaster partitions, metal or wood studs	35
Glazed partitions, bank-height metal or wood studs	30
Baked enamel steel partitions, demountable, full or bank height	25
Vinyl-covered steel partitions, demountable, full or bank height	25
Gypsum plain-finish partitions, movable, full or bank height	20
Gypsum prefinished painted partitions, movable, full or bank height	20
Gypsum vinyl-covered partitions, movable, full or bank height	20
Gypsum plastic-laminated partitions, movable, full or bank height	20
Steel-lined vinyl folding partitions, manual	20
Vinyl clad steel folding partitions, manual	25
Aluminum-faced folding partitions, manual	20
Enameled-steel folding partitions, manual	25
Hardwood veneer folding partitions, manual	25
Plastic-laminated folding partitions, manual	25
Metal baked-enamel toilet partition, frame, door, and hardware	25
Plastic-laminated toilet partition, frame, door, and hardware	25
Stainless steel toilet partition, frame, door, and hardware	35
Porcelain enamel toilet partition, frame, door, and hardware	25
Painted plywood toilet partition, frame, door, and hardware	20
Marble toilet partition, frame, door, and hardware	75

B.6.2 Railing and Handrails

Item Description	Replacement Life (Years)
Steel railing and handrail, pipe, or bar	30
Aluminum railing and handrail	40
Stainless steel railing and handrail	50
Bronze railing and handrail	50
Wood railing and handrail	25

B.6.3 Walls, Floors, and Ceilings

Item Description	Replacement Life (Years)
Wood screen	25
Concrete block	40
Hollow metal door and frame, hardware	30
Hollow-core wood door with metal frame, hardware	20
Solid-core wood door with metal frame, hardware	30
Hollow-core wood door with wood frame, hardware	20
Solid-core wood door with wood frame, hardware	30
Special (security) metal door	40
Plastic laminate wood door	25
Vinyl, light to medium weight	12
Ceramic tile, glazed with organic adhesive	25
Ceramic mosaics, unglazed with organic adhesive	25
Stone veneer	75
Wood veneer, stain, or varnish	40
Oak parquet and block flooring	35
Maple gypsum flooring	35
Resilient asphalt tile, 1/8-in. thick	15
Resilient vinyl tile, 1/8-in. thick	20
Vinyl asbestos tile, 1/8-in. thick	18
Carpeting, standard acrylic or nylon	12
Ceramic tile, glazed with trim, organic adhesive	25
Ceramic mosaics, unglazed with organic adhesive	25
Quarry tile with 3/4-in. Portland cement bed	30
Terrazzo, 2 1/2 to 3-in. thick	50
Brick, unglazed pavers	
Raised access floor: plastic laminate 30- x 30-in. panels	
Raised access floor: carpeted 24- x 24-in. panels	
Raised access floor: carpeted 30- x 30-in. paneled	
Acoustical tile	
Concealed zee splines	10
Exposed 2- x 4-ft grid with hangers	10
Mineral fiber, 12 x 12 in.	12
Mineral fiber lay-in panels with painted face, 24 x 24 in.	15
Exposed 2- x 2-ft grid with hangers	10
Gypsum board, painted	

B.7 Conveying Systems

Item Description	Replacement Life (Years)
Passenger elevators: high speed, automatic (25 HP @ 75% efficiency)	20
Passenger elevators: hydraulic (25 HP @ 75% efficiency)	20
Freight elevators: hydraulic (35 HP @ 75% efficiency)	20
Single-width (32-in.) escalator (7 1/2 HP @ 75% efficiency)	15
Moving walk (4-ft 0-in. wide), (4 HP @ 75% efficiency)	5
Hand-operated dumbwaiter, 1000 lb	20
Electric-operated dumbwaiter, 5000 lb (5 HP @ 75% efficiency)	20

B.8 Mechanical Systems

B.8.1 Plumbing

Item Description	Replacement Life (Years)
Pipe and fittings	
Black steel pipe, schedule 40, 1/2 to 8 in.	30
Copper, type K, including fittings and supports, 1/2 to 2 in.	35
Copper, type L, including fittings and supports, 3/8 to 3 in.	35
Cast iron soil pipe, extra heavy (bell), 2 to 6 in.	40
Cast iron soil pipe, no hub, 1 1/2 to 2 in.	40
Gas and oil pipe	20
Valves	
Bronze gate valves, 3/8 to 1 in.	15
Iron body, bronze mounted gates valves, 6 in.	15
Brass tee and lever handle type, 1/2 to 3/4 in.	15
Hose gate drain valves, bronze 2 in.	15
Shock absorbers, 3/4- to 4-in. long	25
Water meters: disk type, 3/4- to 2-in. diameter	25
Piping insulation	15
Circulating pumps (in-line)	
Iron body circulation pump (1/12 HP)	15
Iron body circulation pump (1/8 HP)	15
Iron body circulation pump (1/2 HP)	15
Domestic hot-water generators	
Gas fired, commercial, cement lined, 70% efficient, 500 gal/hr recovery rate	20
Gas fired, commercial, cement lined, 75% efficient, 100 gal/hr recovery rate	20
Electric heated, residential, glass lined, 100% efficient, 8 to 120 gal/hr recovery rate	20
Floor drains	40
Area drains: cast iron area drains, grate, 3-in. throat	40
Trench drains: light duty, 2- to 4-in. outlet, 2-ft overall	25

Item Description	Replacement Life (Years)
Water closets	
Floor-mounted, wash-down, and siphon jet types	35
Wall-mounted, wash-down, and siphon jet types	35
Urinals	35
Lavatories	
Vitreous china, wall hung	35
Iron enamel, wall hung	40
Enameled steel, wall hung	35
Bathtubs	
Cast-iron enamel	40
Enameled steel	35
Showers	
Terrazzo shower receptor	50
Enameled steel shower receptor	35
Plastic shower receptor	20
Aluminum and glass shower, commercial grade	25
Wash sinks	
Iron enamel, high back, single sink	35
Enameled steel, high back, single sink	35
Stainless steel, high back, single sink	40
Plastic, high back, single sink	15
Drinking fountains: stainless steel electric	20
Meters	
Gas	30
Oil	20
Oil storage tanks	20
Oil pumps	15
Gas compressor	15
Oil preheater (steam)	15
Oil preheater (electric)	10
Insulation	15

B.8.2 Fire Protection Equipment

Item Description	Replacement Life (Years)
Automatic sprinkler system, wet type, concealed piping	20
Simplex-type fire pumps, 20 HP, 500 gpm, 1750 rpm	Life of plant
Fire hose cabinets, primed steel, 25-in. hose, recessed	Life of plant
Siamese connection, brass	Life of plant
Roof manifold, brass (vertical)	Life of plant
Dry chemical enameled steel extinguisher	Life of plant

B.8.3 Heating, Ventilating, and Air Conditioning Equipment

Item Description	Replacement Life (Years)
Boilers	
Packaged marine type (No. 2 oil)	25
Packaged marine type (No. 6 oil)	25
Steel fire box, base, jacket (light oil)	20
Steel fire box, base, packaged	20
Cast-iron sectional with jacket, trim and burner (No. 6 oil)	20
Cast-iron sectional with jacket, trim and burner (steam and gas)	25
Hot water (gas)	20
Hot water (electric)	15
Furnaces	
Up flow, gas fired	20
Up flow, oil fired	20
Up flow, electric heat	15
Horizontal flow, gas fired	20
Pumps	
Horizontal, split case type	20
End suction type	15
Air control	
Boiler fittings	20
Air separators	20
Compression tank and fittings	20
Auxiliary equipment	
Feed water treatment	15
Deaerators	20
Breeching	20
Flues	20
Draft control	15
Heat exchangers	
Direct exchange (DX)	20
Water or steam	20
Heat recovery	15
Equipment insulation	15
Water chilling	
Reciprocating compressor, electric	20
Centrifugal compressor, electric	20
Absorption machine, steam	20
Heat pumps	
Single package, air to air	10
Split system, air to air	15
Cooling towers	
Packaged centrifugal blow through	15
Packaged axial flow	15
Packaged draw through	15
Ejector type	20

Item Description	Replacement Life (Years)
Condensers	
Water cooled	20
Air cooled	20
Evaporative	20
Pipe and fittings	20
Diverting valves	15
Freeze protection	15
Pumps	
Horizontal, split case type	20
End suction	15
Direct expansion system	
Refrigerant circulation system	30
Pipe and fittings	30
Accessories	25
Insulation (piping and equipment)	15
Valves	15
Piping specialties and accessories	10
Distribution systems: steam, glycol, other liquids	20
Air handling equipment	15–20
Air tempering (incremental), through wall type	10
Ductwork	Life of plant
Registers and grills	25
Diffusers	25
Dampers	25
Troffers (light texture type)	20
Air treatment equipment	20
Heat recovery equipment	15
Anti-vibration equipment	15
Insulation	15
Exhaust fans, direct or belt drive	20
Ventilators	20
Make-up air units (inside or outside)	15
Baseboard heating units	
Radiant, cast iron panel	30
Nonferrous element	25
Convector heating units	
Baseboard panel	20
Free standing or semirecessed	25
Induction unit with cabinet	20
Fan coil units with cabinet	20
Radiators, cast iron, free standing	40
Finned tube elements, copper or steel fin type	35
Duct-mounted coil sections	20

Estimated Design Life

Item Description	Replacement Life (Years)
Radiant heating units	
Electric	40
Hot water	25
Unit heaters	
Gas and electric	15
Hot water, steam	20
Space heater, steam/hot water	20
Air curtains, steam/hot water	20
Unit air conditioners with heating	15
Package humidifiers	10
Package dehumidifiers	15
Room thermostats	25
Positional dampers, motor actuated	20
Universal relays	25
Aquastats	25
Simplex air compressor	25
Vacuum pumps, controls and accessories	25
Carbon dioxide cylinders, simplex and duplex	25

B.9 Mechanical Systems

B.9.1 Service and Distribution

B.9.1.1 Low Voltage

Item Description	Replacement Life (Years)
Circuit breakers	Life
Transformers	
Liquid filled	Life
Dry type	30
Switchgear bus, indoor and outdoor, bare, below 600 V	20
Bus duct, indoor and outdoor, all voltages	20
Cable terminations	Life
Motor starters, contact type	18
Motors, synchronous	15
Motors, direct current	15
Motors, induction	15

B.9.1.2 Medium Voltage

Item Description	Replacement Life (Years)
Circuit breakers	Life
Transformers	
Liquid filled	Life
Dry type	30
Switchgear bus, indoor and outdoor, bare or insulated, above 600 V	20
Bus duct, indoor and outdoor, all voltages	20
Cable, thermoplastic, thermosetting, paper insulated, other	Life
Cable joints	Life

B.9.2 Lighting

Item Description	Replacement Life (Years)
Fluorescent interior lighting fixtures	20
Incandescent interior lighting fixtures	20
High-intensity mercury vapor lighting fixtures	20
High-intensity metal-halide (multi-vapor) lighting fixtures	20
High-pressure sodium vapor lighting fixtures	20
Low-pressure sodium vapor lighting fixtures	20

B.9.3 Special Systems

Item Description	Replacement Life (Years)
Generators, steam-turbine driven	25
Generators, gas-turbine driven	25
Generators, reciprocating diesel	25
Baseboard heating units, prewired, including accessories	20

B.10 Specialty Systems

Item Description	Replacement Life (Years)
Canopies	25
Loading docks	20
Tanks	30
Domes (bulk storage, metal framing)	40
Louvers and vents	20
Access floors	25
Integrated ceilings	20
Mezzanine structures	35

Estimated Design Life

B.11 Site Work

B.11.1 Paving Roadways and Walkways

Item Description	Replacement Life (Years)
Curbs	40
Walks	20
Roadways	
Asphalt	15
Concrete	25
Stone/gravel	2

B.11.2 Tunnels

Item Description	Replacement Life (Years)
Electrical	20
Mechanical drainage	40
Mechanical ventilation	25
Structural: arch, circular, columns, beams, walls, structural slabs, joints	Life
Finishes	
Walls	60
Ceilings	45
Floors	25

B.11.3 Security Fences and Gates

Item Description	Replacement Life (Years)
Chain link	25

B.11.4 Bridges and Abutments

Item Description	Replacement Life (Years)
Approaches	
Pavement, asphalt	15
Pavement, concrete	25
Guide railing, concrete	25
Deck Elements	
Curbs, concrete	40
Monodeck surface, concrete	25
Railings/parapets, concrete	25
Sidewalks/fascias, concrete	20
Sidewalks/fascias, steel	40
Wearing surface, asphalt	15
Wearing surface, concrete	25

C
CODES AND STANDARDS

C.1 Purpose

This appendix presents a compilation of various codes and standards associated with maintaining facilities and/or building elements. The appendix is organized into the following sections:

- Federal specifications
- National standards
- Industry publications

The reader should not infer that all standards listed in this appendix were necessarily used in the development of the guidance in this report. Furthermore, this appendix is not inclusive of all pertinent or relevant source material that may be required by a facilities maintenance manager. Many of the documents listed include design, construction, and maintenance guidance.

Care should be taken to ensure that state and local building codes are also considered when designing, constructing, and maintaining facilities because these codes might be more restrictive than those listed here.

C.2 Federal Specifications

DOE 10 CFR 435	DOE Energy Conservation
DOE 29 CFR 1910	Occupational Safety and Health Standards
DOE 40 CFR 112	Oil Pollution Prevention
DOE 40 CFR 141	National Primary Drinking Water Regulations
DOE 40 CFR 290	Underground Storage Tanks
DOE 5460.7	Fire Protection
DOE 6430.1A	DOE General Design Criteria
DOE 9480.7	Fire Protection
FED-STD 372	Test for Critical Radiant Flux of Carpet Flooring Systems (Flooring Radiant Panel Test)
FED-STD 66	(Rev D; Notice 1) Steel, Chemical Composition, and Hardening Ability
FS FF-H-106	Hardware, Builders Locks, and Door Trim
FS FF-H-1619	Hardware, Builders, Auxiliary Locks
FS FF-S-325	(Basic; Int Am 3; Notice 1) Shield, Expansion, Nail, Expansion and Nail, Drive Screw (Devices, Anchoring, Masonry)
FS HH-b526C	Insulation Board, Thermal (Mineral Fiber)
FS HH-b529B	Insulation Board, Thermal (Mineral Aggregate)
FS HH-I 1972/I	Insulation Board, Thermal, Polyurethane or Polyisocyanurate, Faced with Aluminum Foil on Both Sides of the Foam
FS HH-I-1972	Insulation Board, Thermal Faced, Polyurethane or Polyisocyanurate
FS HH-I-524C	Insulation Board, Thermal (Polystyrene)
FS HH-I-5296	Insulation Board, Thermal (Mineral Aggregate)
FS HH-I-551 E	Insulation Block, Pipe Covering and Boards, Thermal (Cellular Glass)
FS HH-I-556	Insulation Blocks, Boards, Blankets, Felts, Sleeving (Pipe and Tube Covering) and Pipe Fitting Covering, Thermal (Mineral Fiber, Industrial Type)
FS HH-M-622	(Rev D) Mortar, Refractory, Heat Setting, Bonding (Wet and Dry Types)
FS HH-R-595B	Roofing Felt Coal-Tar and Asphalt-Saturated Organic Felts, Rolls
FS HH-Y 622	(Rev D) Mortar, Refractory, Heat Setting, Bonding (Wet and Dry Types)
FS I-I-E-509	Enamel, Odorless, Alkyd, Interior, Semi-Gloss, White and Tints
FS I-I-P-641	Primer, Paint Coating, Zinc Dust-Zinc Oxide for Galvanized Surfaces
FS I-I-S-001 992	Stain, Latex, Exterior for Wood Surface
FS IT-E-545	Primer (Enamel-Undercoat, Alkyd, Odorless, Interior/Flat, Tints and White)
FS IT-F-336	Filler, Wood, Paste
FS IT-P-110	Paint, Traffic Black (Nonreflectorized)
FS IT-P-320	Pigment, Aluminum, Powder, and Paste for Paint
FS IT-P-37	Paint, Alkyd Resin, Exterior Trim, Deep Colors
FS IT-P-85	Paint, Traffic and Airfield Marking, Solvent Base
FS IT-S-001 657	Sealing Compound, Single Component, Butyl Rubber Based, Solvent Release Type (for Buildings and Other Types of Construction)

FS IT-V-81	Varnish, Mixing, for Aluminum Paint
FS l-f-P-28	Paint, Aluminum, Heat Resisting (1200°F)
FS l-l-E-487	Enamel: Floor and Deck
FS l-l-E-490	Enamel, Silicone Alkyd Copolymer, Semi-gloss (For Exterior and Interior Nonresistant Use)
FS l-l-E-l 593	Enamel, Silicone Alkyd Copolymer, Gloss (For Exterior and Interior use)
FS LLL-l-535	Insulation Board, Thermal (Cellulosic Fiber) Blocks
FS l-l-P-00791	Putty, Linseed-Oil Type, (for Wood-Sash-Glazing)
FS l-l-P-141 1	Paint, Copolymer-Resin, Cementitious (for Waterproofing Concrete and Masonry Walls)
FS l-l-P-29	Paint, Latex
FS l-l-P-59	Paint, Ready Mixed, International Orange (not for residential use)
FS l-l-S-711	Stain; Oil Type, Wood, Interior
FS l-l-W-572	Wood Preservative: Water-Repellent
FS l-r-C-490	Cleaning Methods for Ferrous Surfaces and Pretreatments for Organic Coatings
FS l-r-C-494	Coating Compound, Bituminous, Solvent Type, Acid Resistant
FS l-r-C-535	Coating, Epoxy, Two Component, for Interior Use on Metal, Wood, Wallboard, Painted Surfaces, Concrete and Masonry
FS l-r-C-542	Coating, Polyurethane, Oil-Free, Moisture Curing
FS l-r-C-555	Coating, Textured (for Interior and Exterior Masonry Surfaces)
FS l-r-E-505	Enamel (Odorless, Alkyd, Interior, High Gloss)
FS l-r-E-508	Enamel, Interior (Semi-Gloss, Tints and White)
FS l-r-F-1098	Filler, Block, Solvent-Thinned, for Porous Surfaces (Concrete Block, Cinder Block, Stucco, etc.)
FS l-r-l-735	Isopropyl Alcohol
FS l-r-P-102	Paint, Oil, Alkyd Modified, Exterior, White and Tints
FS l-r-P-1 10	Paint, Traffic Black (Nonreflectorized)
FS l-r-P-115	Paint, Traffic, (Highway, White, and Yellow)
FS l-r-P-1511	Paint, Latex (Gloss and Semi-Gloss, Tints and White), (for Interior Use)
FS l-r-P-30	Paint, Alkyd, Odorless, Interior, Flat, White and Tints
FS l-r-P-31	Paint, Oil: Iron-Oxide, Ready-Mixed, Red and Brown
FS l-r-P-38	Paint, Aluminum (Ready-Mixed)
FS l-r-P-650	Primer Coating, Latex Base, Interior, White (for Gypsum Wallboard, or Plaster)
FS l-r-P-664	Primer Coating, Alkyd, Corrosion-Inhibiting, Lead- and Chromate-Free, Noncompliant
FS l-r-P-88	Paint, Red-Lead Based, Ready-Mixed
FS l-r-P-91	Paint, Rubber-Base, for Interior Use (Concrete and Masonry Floors)
FS l-r-R-266	Resin, Alkyd, Solutions
FS l-r-S-00230	Sealing Compound, Elastomeric Type, Single Component for Caulking, Sealing, and Glazing (for Buildings and Other Structures)
FS l-r-S-708	Stain, Oil; Semi-Transparent, Wood, Exterior

FS l-r-T-291	Thinner, Paint, Mineral Spirits, Regular and Odorless
FS l-r-T-291	Thinner, Paint, Mineral Spirits, Regular and Odorless
FS l-r-v-109	Varnish, Interior, Alkyd-Resin
FS l-r-v-119	Varnish, Spar, Phenolic-Resin
FS l-r-v-121	Varnish, Spar, Water Resisting
FS l-r-V-51	Varnish, Asphalt
FS l-r-V-65	Varnish, Oil, (Low Sheen, Brush or Spray Application)
FS l-r-V-86	Varnish, Oil, Rubbing (for Metal and Wood Furniture)
FS l-r-w-00571	Wood Preservation: Treating Practices
FS L-S-125	Screening, Insect, Nonmetallic
FS lT.P-38	Paint, Aluminum (Ready-Mixed)
FS lT-C-490	Cleaning Methods for Ferrous Surfaces and Pretreatments for Organic Coatings
FS lT-C-498	Coating Compound, Bituminous, Fillers, Solvent Type, Aluminum Pigmented
FS lT-C-555	Coating, Textured (for Interior and Exterior Masonry Surfaces)
FS lT-F-1098	Filler, Block, Solvent-Thinned, for Porous Surfaces (Concrete Block, Cinder Block, Stucco, etc.)
FS lT-P-00791	Putty,-Linseed-Oil Type, (For Wood-Sash-Glazing)
FS lT-P-1411	Paint, Copolymer-Resin, Cementitious (For Waterproofing Concrete and Masonry Walls)
FS lT-P-1728	Paint, Latex-Base, Interior, Flat, Deep Tone
FS lT-P-28	Paint, Aluminum, Heat Resisting (1200°F)
FS l-T-P-641	Primer, Paint Coating, Zinc Dust-Zinc Oxide for Galvanized Surfaces
FS l-T-P-645	Primer, Paint, Zinc-Chromate, Alkyd Type
FS l-T-P-815	Primer Coating: Basic Lead Silicon Chromate, Ready-Mixed
FS l-T-P-85	Paint, Traffic and Airfield Marking, Solvent Base
FS lT-P-86	Paint, Red-Lead-Base, Ready-Mixed
FS lT-R-266	Resin, Alkyd, Solutions
FS lT-S-001543	Sealing Compound: Silicone Rubber Base (for Caulking, Sealing, and Glazing in Buildings and Other Structures)
FS lT-S-001657	Joint and Seam Sealant
FS lT-S-00227	Sealing Compound, Elastomeric Type, Multi-Component for Caulking, Sealing, and Glazing (for Buildings and Other Structures)
FS lT-S-00230	Sealing Compound, Elastomeric Type, Single-Component for Caulking, Sealing, and Glazing (for Buildings and Other Structures)
FS lT-S-176	Sealer, Surface, Varnish Type, Floor, Wood or Cork
FS lT-S-227E	Cant Strip
FS lT-V-119	Varnish, Spat, Phenolic-Resin
FS lT-V-85	Varnish, Oil, (Low Sheen, Brush or Spray Application)
FS lT-W-00571	Wood Preservation: Treating Practices
FS lT-W-572	Wood Preservative: Water-Repellant
FS ma-s-775	Steel Sheets, Carbon, Zinc-Coated (Galvanized) by the Hot-Dip Process

FS m-E-496	Enamel: Heat-Resisting (400°F), Black
FS MM-L-738	Lumber, Hardwood
FS MM-L-751	Lumber, Softwood
FS MMM-A-001993	(Basic) Adhesive, Epoxy, Flexible, Filled (for Binding, Sealing and Grouting)
FS MM-P-371	Lumber Piles and Poles, Wood
FS m-P-19	Paint, Latex (Acrylic Emulsion, Exterior Wood and Masonry)
FS m-P-24	Paint, Oil, Concrete and Masonry, Exterior Eggshell Finish Ready- Mixed
FS m-P-37	Paint, Alkyd Resin, Exterior Trim, Deep Colors
FS m-P-664	Primer Coating, Alkyd, Corrosion-Inhibiting, Lead and Chromate Free
FS n-P-95	Paint, Rubber: for Swimming Pools and Other Concrete and Masonry Surfaces
FS QQ S-775	(Rev E; Int Am 1) Steel Sheets, Carbon, Zinc-Coated (Galvanized)by the Hot-Dip Process
FS QQ-C-40	Caulking: Lead Wool and Lead Pig
FS QQ-S-763	(Rev E; Am 1; Notice 1) Steel Bars, Wire, Shapes, and Forgings, Corrosion Resisting
FS QQ-S-763	(Rev E; Am 1; Notice 1) Steel Bars, Wire, Shapes, and Forgings, Corrosion Resisting
FS QQ-S-775	(Rev E; Int Am 1) Steel Sheets, Carbon, Zinc-Coated (Galvanized) by the Hot-Dip Process
FS QQ-T-201	Template, for Roofing and Roofing Products
FS QQ-W461	(Rev H) Wire, Steel, Carbon (Round, Bare, and Coated)
FS RR F-191/ID	Fencing, Wire and Post, Metal (Chain-Link Fence Fabric)
FS RR-B-191	(Rev B) Bedpan, Corrosion-Resisting Steel
FS RR-D-575	Door, Metal, Sliding and Swinging: Door Frame, Metal (Flush and Semiflush)
FS RR-F-191 K/GEN	Fencing, Wire and Post, Metal (Chain-Link Fence Fabric and Accessories)
FS RR-F-191/2D	Fencing, Wire and Post, Metal (Chain-Link Fence Gates)
FS RR-F-221 G/GEN	Fencing, Wire, Fence Posts and Accessories (Barbed Wire, Woven Wire, and Netting)
FS RR-F-l91/3D	Fencing, Wire and Post, Metal (Chain-Link Fence Posts, Top Rails and Braces)
FS RR-F-l91/4D	Fencing, Wire and Post, Metal (Chain-Link Fence Accessories)
FS SS-A-666D	Asphalt, Petroleum (Built-Up Roofing, Waterproofing and Dampproofing)
FS SS-A-694D	Asphalt, Petroleum (Primer, Roofing and Waterproofing)
FS SS-A-701	Asphalt, Petroleum (Primer, Roofing and Waterproofing)
FS SS-C-153	Cement, Bituminous, Plastic
FS SS-C-156	Federal Specification for Cements, Hydraulic, General Specifications (methods for sampling, inspection, and testing)
FS SS-C-161	Federal Specification for Cement, Masonry
FS SS-C-192	Federal Specification for Cements, Portland (10 types)
FS SS-C-206	Federal Specification for Cement, Portland, Pozzolana
FS SS-C-450A	Cloth, Impregnated (Woven Cotton Cloth, Asphalt Impregnated, Coal-Tar Impregnated)

FS SS-G-192	Federal Specification for Cements, Portland (10 types)
FS SSG-450A	Cloth, Impregnated (Woven Cotton Cloth, Asphalt Impregnated, Coal-Tar Impregnated)
FS SS-P-00402	Plaster, Gypsum
FS SS-R-501 D	Roofing Felt, Asphalt-Prepared, Smooth Surfaced
FS SS-R-630D	Roofing Felt, (Roll, Asphalt-Prepared, Mineral-Surfaced)
FS SS-S-210	Sealing Compound, Preformed Plastic, for Expansion Joints and Pipe Joints
FS SS-T-312	Tile, Floor: Asphalt, Rubber, Vinyl, and Vinyl Composition
FS SS-W-40	Wall Base: Rubber, and Vinyl Plastic
FS Tf-S-300	Shellac, Cut
FS Tl-C-1796	Caulking Compounds, Metal Seam and Wood Seam
FS T-l-P-1510	Paint, Latex, Exterior, for Wood Surfaces, White and Tints
FS Tl-P-615	Primer Coating: Basic Lead Silica Chromate, Ready Mixed
FS T-r-C-535	Coating, Epoxy, Two Component, for Interior Use on Metal, Wood, Wallboard, Painted Surfaces, Concrete and Masonry
FS T-r-F-338	Filler, Wood, Paste
FS T-r-P-002119	Paint, Latex Base, High Traffic Area, Flat and Eggshell Finish (Low Lustre), (for Interior Use)
FS T-r-P-1952	Paint, Traffic and Airfield Marking, Water Emulsion Base
FS T-r-P-320	Pigment, Aluminum, Powder and Paste for Paint
FS TT-C-00598	Caulking Compound, Oil and Resin Base Type (for Building Construction)
FS TT-C-498	Coating Compound, Bituminous, Fillers, Solvent Type, Aluminum Pigmented
FS TT-E-487	Enamel: Floor and Deck
FS TT-E-489	Enamel, Alkyd, Gloss, Low VOC Content
FS TT-E-490	Enamel, Silicone Alkyd Copolymer, Semi-Gloss (for Exterior and Interior Nonresistant Use)
FS TT-E-491	Enamel, Glass, Synthetic (for Metal and Wood Furniture)
FS TT-E-506	Enamel, Alkyd, Gloss, Tints and White (for Interior Use)
FS TT-l-735	Isopropyl Alcohol
FS TT-P-001984	Primer Coating, Latex Base, Exterior, (Undercoat for Wood), White and Tints
FS TT-P-31	Paint, Oil: Iron-Oxide, Ready-Mixed, Red and Brown
FS TT-P-59	Paint, Ready Mixed, International Orange (Not for Residential Use)
FS TT-V-61	Varnish, Mixing, for Aluminum Paint
FS UU-B-790	Building Paper, Vegetable Fiber: (Kraft, Water-proofed, Water Repellent and Fire Resistant)
FS UU-P-268	Paper, Kraft, Wrapping
FS UU-P-270	Paper, Wrapping, Waxed (Dry)
FS VT-P-645	Primer, Paint, Zinc-Chromate, Alkyd Type
FS WW-P-460b	Pipe Fittings, Bronze, Cast
FS WW-P-47b	Pipe Fittings, Ferrous, Threaded
FS WW-P-480b	Pipe Fittings, Bronze, Cast

FS WW-P-541	Plumbing Fixtures
FS ZZ-C-00811	Cushion, Carpet and Rug, Cellular Rubber
FS ZZ-l-001237	Tread, Stair, Flexible and Semi-Rigid Type Rubber and Vinyl
FS ZZ-R-785/GEN	Rubber, Silicone
FS-l-r-E-496	Enamel: Heat-Resisting (400°F), Black
GSA PBS P 5650.18	Maintenance Guidelines
REA Bulletin 160-2	Rural Electrical Association - Mechanical Design Manual for Overhead Distribution Lines
REA Bulletin 163-l	Rural Electrical Association - Steam-Electric Generating Plants, Operation and Maintenance Inspection Manual
REA Bulletin 169-l	Rural Electrical Association - The Application of Shunt Capacitors of the Rural Electric System
REA Bulletin 43-5	Rural Electrical Association - List of Materials Acceptable for Use on Systems of REA Electrification Borrowers
REA Bulletin 50-2	Rural Electrical Association - Electric Transmission Specifications and Drawings, 34.5 kV Through 69 kV
REA Bulletin 50-l	Rural Electrical Association - Electric Transmission Specifications and Drawings, 115kV Through 230 kV
REA Bulletin 61-l2	Rural Electrical Association - Guide for Narrow Profile and Armless Construction (Electric Distribution)
USCE CRD C400	Requirements for Water for Use in Mixing or Curing Concrete
USCE CRD-C109	Field Test for Absorption by Aggregates
USCE CRD-C119	Test for Flat and Elongated Particles in Coarse Aggregates
USCE CRD-C129	Test for Particles of Low Specific Gravity in Coarse Aggregate (Sink-Float Test)
USCE CRD-C213	Test for the Presence of Sugar in Cement, Mortar, Concrete, and Aggregates
USCE CRD-C248	Test for the Presence of Sugar in Cement, Mortar, Concrete, and Aggregates
USCE CRD-C300	Specifications for Pigmented Membrane-Forming Compounds for Curing Concrete
USCE CRD-C400	Requirements for Water for Use in Mixing or Curing Concrete
USCE CRD-Cl09	Field Test for Absorption by Aggregates
USCE CRD-Cl19	Test for Flat and Elongated Particles in Coarse Aggregates
USCE CRD-Cl29	Test for Particles of Low Specific Gravity in Coarse Aggregate (Sink-Float Test)
USCE CRD-Cl3	Test for Evaluation of Air-Entraining Admixtures for Concrete

C.3 National Standards

C.3.1 Air Conditioning and Refrigeration Institute (ARI)

Standard	Title of Standard
ARI 1010	Drinking Fountains and Self-Contained Mechanically Refrigerated Drinking Water Coolers
ARI 210	Standard for Unitary Air Conditioning Equipment
ARI 270	Standard for Sound Rating of Outdoor Unitary Equipment
ARI 330	Unit Ventilators
ARI 360	Standard for Commercial and Industrial Unitary Air Conditioning Equipment
ARI 410	Forced-Circulation Air-Cooling and Air-Heating Coils
ARI 430	Central-Station Air-Handling Units
ARI 440	Room Fan-Coil Air Conditioners
ARI 450	Water Cooled Refrigerant Condensers, Remote
ARI 460	Remote Mechanical-Draft Air Cooled Refrigerant Compressors
ARI 520	Positive Displacement Refrigerant Compressors and Condensing Units
ARI 550	Centrifugal or Rotary Water-Chilling
ARI 590	Packages Reciprocating Water-Chilling Packages
ARI 610	Standard for Central System Humidifiers
ARI 620	Standard for Self-Contained Humidifiers
ARI 630	Standard for Selection, Installation, and Servicing of Humidifiers
ARI 650	Commercial and Industrial Air Filter Equipment
ARI 660	Industry Standard for Air Terminals
ARI 850	Standard for Air Outlets and Inlets

C.3.2 Air Movement and Control Association (AMCA)

Standard	Title of Standard
AMCA 201	Fans and Systems
AMCA 210	Laboratory Methods of Testing Fans for Rating Purposes
AMCA 300	Test Code for Sound Rating
AMCA 301	Method for Calculating Fan Sound Ratings from Laboratory Test Data
AMCA 500	Test Method for Louvers, Dampers, and Shutters
AMCA 99	Standards Handbook

C.3.3 American Architectural Manufacturers Association (AAMA)

Standard	Title of Standard
AAMA 101	Voluntary Specifications for Aluminum Prime and Sliding Glass Doors
AAMA 603	Voluntary Performance Requirements and Test Procedures for Pigmented Organic Coatings on Extruded Aluminum
AAMA 605.2	Voluntary Specification for High Performance Organic Coatings on Architectural Extrusions and Panels
AAMA 606.1	Voluntary Guide Specifications and Inspection Methods for Integral Color Anodic Finishes for Architectural Aluminum
AAMA 607.1	Voluntary Guide Specification and Inspection Methods for Clear Anodic Finishes for Architectural Aluminum
AAMA 608.1	Voluntary Guide Specification and Inspection Methods for Electrolytically Deposited Color Anodic Finishes for Architectural Aluminum
AAMA WSG-1	Window Selection Guide

C.3.4 American Association of Textile Colorists and Chemists (AATCC)

Standard	Title of Standard
AATCC 100	Assessment of Anti-Bacterial Finishes on Textile Materials
AATCC 134	Electrostatic Propensity of Carpets
AATCC 30	Anti-Fungal Activity Assessment on Textile Materials; Mildew and Rot Resistance of Textile Materials

C.3.5 American Concrete Institute (ACI)

Standard	Title of Standard
ACI 117	Standard Tolerances for Concrete Construction and Materials
ACI 211.2	Standard Practice for Selecting Proportions for Structural Lightweight Concrete
ACI 211.3	Standard Practice for Selecting Proportions for No-Slump Concrete
ACI 211.88	Standard Practice of Selecting Proportions for Normal, Heavyweight, and Mass Concrete
ACI 301	Specifications for Structural Concrete for Buildings
ACI 304R	Guide for Measuring, Mixing, Transporting, and Placing Concrete
ACI 305R-89	Hot Weather Concreting
ACI 306R-88	Cold Weather Concreting
ACI 308	Standard Practice for Curing Concrete
ACI 309	Standard Practice for Consolidation of Concrete
ACI 315	Details and Detailing of Concrete Reinforcements
ACI 316	Recommendations for Construction of Concrete Pavements and Concrete Bases
ACI 318	Building Code Requirements for Reinforced Concrete
ACI 336.1-89	Standard Specification for the Construction of End Bearing Drilled Piers
ACI 347	Recommended Practice for Concrete Formwork
ACI 506R	Shotcrete

C.3.6 American Hardboard Association (AHA)

Standard	Title of Standard
AHA AI 35.6	Hardboard Siding

C.3.7 American Institute of Steel Construction (AISC)

Standard	Title of Standard
AISC M013	Detailing for Steel Construction
AISC M014	Engineering for Steel Construction - The Source Book of Connections
AISC M015L	Load and Resistance Factor Design (LRFD) Manual of Steel Construction
AISC M018	Manual of Steel Construction ASD
AISC S302	Code of Standard Practice for Steel Buildings and Bridges
AISC S329	Allowable Stress Design Specification for Structural Joints Using ASTM A325 or ASTM A490 Bolts
AISC S335	Specification of Structural Steel Buildings – Allowable Stress Design and Plastic Design

C.3.8 American Institute of Timber Constructions (AITC)

Standard	Title of Standard
AITC 01	Timber Construction Manual
AITC 111	Recommended Practice for Protection of Structural Glued Laminated Timber During Transit, Storage, and Erection
AITC 112	Tongue-and-Groove Heavy Timber Roof Decking
AITC 117	Structural Glued Laminated Timber of Softwood Species, Design Requirements
AITC 200	Inspection Manual
AITC A190.1	Structural Glued Laminated Timber

C.3.9 American Iron and Steel Institute (AISI)

Standard	Title of Standard
AISI SG-671	Cold-Formed Steel Design Manual: Part I – Design of Cold-Formed Steel Structural Members
AISI SG-673	Cold-Formed Steel Design Manual

C.3.10American National Standards Institute (ANSI)

Standard	Title of Standard
ANSI 253.9	Gas-Fired Duct Furnaces
ANSI 263.6	Gas Unit Heaters
ANSI A58.1	Minimum Design Loads for Buildings and Other Structures
ANSI B16.4	Cast-Iron Threaded Fittings
ANSI B16.5	Steel Flanges and Flanged Fittings
ANSI B31.5	ASME Code for Pressure Piping - Refrigerant Piping

Standard	Title of Standard
ANSI B9.1	Safety Code Requirements Pertaining to Unit Construction of Reciprocating Chillers

C.3.11 American Plywood Association (APA)

Standard	Title of Standard
APA AFG-01	Adhesives for Field-Gluing Plywood to Wood Framing
APA Form E30	Design/Construction Guide, Residential and Commercial
APA PRP-108	Performance Standards and Policies for Structural-Use Panels

C.3.12 American Society for Testing and Materials (ASTM)

Standard	Title of Standard
ASTM 02659	Test Method for Flammability of Finished Textile Floor Covering Materials
ASTM 04397	Specifications for Polyethylene Sheeting for Construction, Industrial, and Agricultural Applications
ASTM 25-89	Specification for Round Timber Piles
ASTM A104	Specification for Fabricated Deformed Steel Bar Mats for Concrete Reinforcement
ASTM A105	Specification for Welded Steel Wire Fabric for Concrete Reinforcement
ASTM A143	Safeguarding Against Embrittlement of Hot-Dip Galvanized Structural Steel Products and Procedure for Detecting Embrittlement
ASTM A146	Steel Castings, High Strength, for Structural Purposes
ASTM A164	Fabricated Deformed Steel Bar Mats for Concrete Reinforcement
ASTM A165	Steel We1ded Wire Fabric, Plain, for Concrete Reinforcement
ASTM A211	Spiral-Welded Steel or Iron Pipe
ASTM A234	Steel Fittings
ASTM A242	High-Strength Low-Alloy Structural Steel
ASTM A252-09	Specification for Welded and Seamless Steel Pipe Piles
ASTM A276	Float and Thermostatic Traps
ASTM A325	High-Strength Bolts for Structural Steel Joints
ASTM A36	Structural Steel
ASTM A366	Carbon Steel Sheets
ASTM A416-88	Specification for Uncoated Seven-Wire Stress-Relieved Steel for Prestressed Concrete
ASTM A421	Specification for Uncoated Stress-Relieved Wire for Prestressed Concrete
ASTM A444-09	Specification for Steel Sheet, Zinc-Coated (Galvanized) by the Hot-Dipped Process for Storm Sewer and Drainage Pipe
ASTM A446	Specification for Steel Sheet, Zinc-Coated (Galvanized) by the Hot-Dip Process, Structural (Physical) Quality
ASTM A460	Stainless Steel Sheets
ASTM A467	Steel Welded Wire Fabric, Deformed, for Concrete Reinforcement
ASTM A47	Malleable-Iron Pipe Fittings

Standard	Title of Standard
ASTM A49	Heat-Treated Carbon Steel Joint Bars
ASTM A490	Stainless Steel Sheets
ASTM A496	Specification for Deformed Steel Wire for Concrete Reinforcement
ASTM A497	Specification for Welded Deformed Steel Wire Fabric for Concrete Reinforcement
ASTM A525	Specification for Steel Sheet, Zinc-Coated (Galvanized) by the Hot-Dip Process
ASTM A526	Galvanized Steel for Panel Surfaces, Internal Channels, And Trim Items
ASTM A527	Galvanized Steel as Used in Breechings
ASTM A529	Structural Steel with 42 ksi (290 MPa) Minimum Yield Point l/2 in. (13 micrometer) Maximum Thickness
ASTM A53	Steel Pipe
ASTM A536	Ductile-Iron Pipe Fittings
ASTM A562	Steel Structural Rivets
ASTM A568	High-Strength Low-Alloy Structural Steel with 50 ksi (345 MPa) Minimum Yield Point to 4 in. (100 micrometer) Thick
ASTM A569	Black, Carbon, Hot-Rolled Steel as Used in Breechings
ASTM A6	Rolled Steel Plates, Shapes, Sheet Piling, and Bars for Structural Use
ASTM A611	Steel, Sheet, Carbon, Cold-Rolled, Structural Quality
ASTM A615	Deformed and Plain Billet-Steel Bars for Concrete Reinforcement Rail-Steel Deformed and Plain Bars for Concrete Reinforcement
ASTM A615-89	Specification for Deformed and Plain Billet-Steel Bars for Concrete Reinforcement
ASTM A616	Axle-Steel Deformed and Plain Bars for Concrete Reinforcement
ASTM A617	Specification for Axle-Steel Deformed and Plain Bars for Concrete Reinforcement
ASTM A62	Steel Wire, Plain, for Concrete Reinforcement
ASTM A63	Steel Pipe
ASTM A633	Normalized High-Strength Low-Alloy Structural Steel
ASTM A641	Specification for Zinc-Coated (Galvanized) Carbon Steel Wire
ASTM A706	Low-Alloy Steel Deformed Bars for Concrete Reinforcement
ASTM A722	Uncoated High-Strength Steel Bar for Prestressing Concrete
ASTM A767-89	Standard Specification for Zinc-Coated (Galvanized) Bars for Concrete Reinforcement
ASTM A82-88	Specification for Steel Wire, Plain, for Concrete Reinforcement
ASTM Al06	Steel Pipe Fittings
ASTM Al20	Steel Pipe
ASTM Al26	Cast-Iron Valves
ASTM B62	Bronze Valves
ASTM B66	Copper Tubing As Drawn Temper, Type L Or Annealed Type K
ASTM B117	Erosion Testing Of Cooling Towers
ASTM B18.4	Cast Iron Threaded Fittings
ASTM B18.5	Steel Flanges and Flanged Fittings
ASTM B209	Aluminum Sheets

Standard	Title of Standard
ASTM B280	Copper Tubing Type ACR
ASTM B31.5	ASME Code for Pressure Piping – Refrigerant Pipings
ASTM C1050	Rigid Cellular Polyurethane Composite Roof Insulation
ASTM C1071	Duct Liner
ASTM C109	Test for Compressive Strength of Hydraulic Cement Mortars
ASTM C114	Methods for Chemical Analysis of Portland Cement
ASTM C115	Test for Fineness of Portland Cement by the Turbidimeter
ASTM C117	Test for Materials Finer Than No. 200 Sieve in Mineral Aggregates by Washing
ASTM C123	Test for Lightweight Pieces in Aggregate
ASTM C125	Definitions of Terms Relating to Concrete and Concrete Aggregates
ASTM C127	Test for Specific Gravity and Absorption of Coarse Aggregate
ASTM C128	Test for Specific Gravity and Absorption of Fine Aggregate
ASTM C131	Test for Resistance to Abrasion of Small Size Coarse Aggregate by use of the Los Angeles Machine
ASTM C136	Test for Sieve or Screen Analysis of Fine and Coarse Aggregates
ASTM C141	Specification for Hydraulic Hydrated Lime for Structural Purposes
ASTM C143-90	Standard Test Method for Slump of Portland Cement Concrete
ASTM C144	Specification for Aggregate for Masonry Mortar
ASTM C150	Specification for Portland Cement (Eight types)
ASTM C150-89	Specification for Portland Cement
ASTM C151	Autoclave Expansion of Portland Cement
ASTM C156	Water Retention by Concrete Curing Materials
ASTM C171	Specification for Sheet Materials for Curing Concrete
ASTM C172-90	Standard Method of Sampling Freshly Mixed Concrete
ASTM C183	Methods of Sampling Hydraulic Cement
ASTM C184	Test for Fineness of Hydraulic Cement by the No. 100 and No. 200 Sieves
ASTM C186	Test for Heat of Hydration of Hydraulic Cement
ASTM C187	Test for Density of Hydraulic Cement
ASTM C188	Test for Normal Consistency of Hydraulic Cement
ASTM C190	Test for Tensile Strength of Hydraulic Cement Mortars
ASTM C191	Test for Time of Setting of Hydraulic Cement by Vicat Needle
ASTM C204	Test for Fineness of Portland Cement by Air Permeability Apparatus
ASTM C206	Specification for Finishing Hydrated Lime
ASTM C207	Specification for Hydrated Lime for Masonry Purposes
ASTM C208	Insulating Board (Cellulosic Fiber), Structural and Decorative
ASTM C219	Definitions of Terms Relating to Hydraulic Cement
ASTM C2-1990	National Electrical Safety Code
ASTM C226	Specification for Air-Entraining Additions for Use in the Manufacture of Air-Entraining Cement
ASTM C227	Test for Potential Alkali Reactivity of Cement-Aggregate Combinations

Standard	Title of Standard
ASTM C230	Specification for Flow Table for Use in Tests of Hydraulic Cement
ASTM C233	Method of Testing Air-Entraining Admixtures for Concrete
ASTM C241	Test Method for Abrasion Resistance of Stone Subjected to Foot Traffic
ASTM C243	Test for Bleeding of Cement Pastes and Mortars
ASTM C260	Specification for Air-Entraining Admixtures for Concrete
ASTM C260-86	Specification for Air-Entraining Admixtures for Concrete
ASTM C265	Test for Calcium Sulfate in Hydrated Portland Cement Mortar
ASTM C266	Test for Time of Setting of Hydraulic Cement by Gillmore Needles
ASTM C267	Chemical Resistance of Mortars, Grouts, and Monolithic Surfacings
ASTM C270	Specification for Mortar for Unit Masonry
ASTM C287	Test for Chemical Resistance of Mortars
ASTM C29	Test for Unit Weight and Voids in Aggregate
ASTM C295	Recommended Practice for Petrographic Examination of Aggregates for Concrete
ASTM C309	Specification for Liquid Membrane-Forming Compounds for Curing Concrete
ASTM C31	Making and Curing Concrete Test Specimens in the Field
ASTM C311	Sampling and Testing Fly Ash and Raw or Calcined natural Pozolan for Use as a Mineral Admixture in Portland Cement Concrete
ASTM C31-90	Standard Methods of Making and Curing Concrete Test Specimens In the Field
ASTM C33	Specification for Concrete Aggregates
ASTM C330	Specification for Lightweight Aggregates for Structural Concrete
ASTM C331	Specification for Lightweight Aggregates for Concrete Masonry Units
ASTM C332	Specification for Lightweight Aggregates for Insulating Concrete
ASTM C33-90	Specification for Concrete Aggregate
ASTM C36	Specification for Gypsum Wallboard
ASTM C39	Compressive Strength of Cylindrical Concrete Specimens
ASTM C39-86	Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens
ASTM C40	Organic Impurities in Fine Aggregates for Concrete
ASTM C40	Test for Organic Impurities in Sands for Concrete
ASTM C423	Test Method for Sound Absorption of Acoustical Materials by Reverberation Room Method
ASTM C442	Specification for Gypsum Backing Board and Coreboard
ASTM C465	Specification for Processing Additions for Use in Manufacture of Hydraulic Cements
ASTM C475	Specification for Joint Treatment Materials for Gypsum Wallboard Construction
ASTM C494-86	Specification for Chemical Admixtures for Concrete
ASTM C5	Specification for Quicklime for Structural Purposes
ASTM C501	Specification for Marble Building Stone
ASTM C514	Specification for Nails for the Application of Gypsum Wallboard

Standard	Title of Standard
ASTM C535	Test for Resistance to Abrasion of large Size Coarse Aggregate by use of the Los Angeles Machine
ASTM C552	Cellular Glass Block and Pipe Thermal Insulation
ASTM C557	Specification for Adhesives for Fastening Gypsum Wallboard to Wood Framing
ASTM C578	Preformed, Cellular Polystyrene Thermal Insulation
ASTM C595	Specification for Blended Hydraulic Cements
ASTM C6	Specification for Normal Finishing Hydrated Lime
ASTM C629	Specification for Slate Building Stone
ASTM C630	Specification for Water-Resistant Gypsum Backing Board
ASTM C635	Specification for Metal Suspension Systems for Acoustical Tile and Lay-In Panel Ceilings
ASTM C636	Practice for Installation of Metal Ceiling Suspension Systems for Acoustical Tile and Lay-In Panels
ASTM C640	Specification for Application and Finishing of Gypsum Board
ASTM C645	Specification for Non-Load (Axial) Bearing Steel Studs, Runners (Track) and Rigid Furring Channels for Screw Application of Gypsum Board
ASTM C647	Specification for Metal Lath
ASTM C651	Recommended Practice for Estimating Scratch Hardness of Coarse Aggregate Particles
ASTM C665	Specification for Mineral Fiber Blanket Thermal Insulation for Light Frame Construction and Manufactured Housing
ASTM C70	Surface Moisture in Fine Aggregate
ASTM C726	Mineral Fiber and Mineral Fiber, Rigid Cellular Polyurethane Composite Roof Insulation Board
ASTM C728	Perlite Thermal Insulation Board
ASTM C754	Specification for Installation of Steel Framing Members to Receive Screw-Attached Gypsum Wallboard, Backing Board, or Water-Resistant Backing Board
ASTM C78	Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading)
ASTM C851	Recommended Practice for Estimating Scratch Hardness of Course Aggregate Particles
ASTM C87	Test for Effect of Organic Impurities in Fine Aggregate on Strength of Mortar
ASTM C88	Test for Soundness of Aggregates by Use of Sodium Sulfate or Magnesium Sulfate
ASTM C91	Specification for Masonry Cement
ASTM C916.9	Liner Adhesive
ASTM C919	Practices for Use of Sealants in Acoustical Applications
ASTM C920	Specification for Elastomeric Joint Sealants
ASTM C94	Specification for Ready-Mixed Concrete
ASTM C94-90	Specification for Ready-Mixed Concrete
ASTM C94-96	Standard Test Method for Ready-Mixed Concrete
ASTM C951	Recommended Practice for Estimating Scratch Hardness of Coarse Aggregate Particles

Standard	Title of Standard
ASTM C957	Elastomeric Coating
ASTM C964	Perlite Board, Rigid Cellular Polyurethane Composite Roof Insulation
ASTM C984	Perlite Board
ASTM CI002	Specification for Steel Drill Screws for Application of Gypsum Board
ASTM CI050	Rigid Cellular Polyurethane Composite Roof Insulation
ASTM CI50-90	Standard Specification for Portland Cement
ASTM CI51	Test for Autoclave Expansion of Portland Cement
ASTM CI58	Test for Water Retention by Concrete Curing Materials
ASTM D150047	Test Method for ASTM Color of Petroleum Products (ASTM Color Scale)
ASTM D 1524-U	Test Method for Visual Examination of Used Electrical Insulating Oils of Petroleum Origin in the Field
ASTM D877-87	Test Method for Dielectric Breakdown Voltage of Insulating Liquids Using Disk Electrodes
ASTM D924-65	Test method for A-C Loss Characteristics and Relative Permittivity (Dielectric Constant) of Electrical Insulating Liquids
ASTM D971-82	Test Method for Interfacial Tension of Oil Against Water by the Ring Method
ASTM D974-87	Test Method for Acid and Base Number by Color-Indicator Titration
ASTM D1066	Sampling Steam
ASTM D1067	Tests for Acidity or Alkalinity of Water
ASTM D1068	Tests for Iron in Water
ASTM D1079	Definition of Terms Relating to Roofing, Waterproofing, and Bituminous Materials
ASTM D1126	Tests for Hardness in Water
ASTM D1143-91	Method of Testing Piles Under Static Axial Compressive Load
ASTM D1187	UH-Reinforced Bituminous Emulsion
ASTM D1227	Emulsified Asphalt Used as a Protective Coating for Built-Up Roofing
ASTM D1327	Bitumen-Saturated Woven Burlap Fabrics Used in Roofing and Waterproofing
ASTM D1668	Glass Fabrics (Woven and Treated) for Roofing and Waterproofing
ASTM D173	Bitumin/Saturated Cotton Fabric
ASTM D1779	Specification for Adhesive for Acoustical Materials
ASTM D1863	Mineral Aggregate Used on Built-Up Roofs
ASTM D1888	Tests for Particulate and Dissolved Matter in Water
ASTM D2166-85	Standard Test Methods for Unconfined Compressive Strength of Cohesive Soil
ASTM D2178	Asphalt Glass Felt Used in Roofing and Waterproofing
ASTM D2216-80	Standard Method for Laboratory Determination of Water (Moisture) Content of Soil, Rock, and Soil-Aggregate Mixtures
ASTM D224	Smooth-Surfaced Asphalt Roll Roofing (Organic Felt)
ASTM D226	Asphalt-Saturated Organic Felt Used in Roofing and Waterproofing
ASTM D227	Coal-Tar-Saturated Organic Felt Used in Roofing and Waterproofing
ASTM D249	Asphalt Roll Roofing (Organic Felt) Surfaced with Mineral Granules
ASTM D2626	Asphalt-Saturated and Coated Organic Felt Base Sheet Used In Roofing

Standard	Title of Standard
ASTM D2794	Impact Testing of Cooling Towers
ASTM D2822	Asphalt Roof Cement
ASTM D2823	Asphalt Roof Coatings
ASTM D2824	Aluminum-Pigmented Asphalt Roof Coatings
ASTM D2829	Recommended Practice for Sampling and Analysis of Built-Up Roofs
ASTM D2846	Chlorinated Polyvinyl Chloride (CPVC) Pipe
ASTM D312	Asphalt Used in Roofing
ASTM D3370	Practices for Sampling Water
ASTM D3574	Method of Testing Flexible Cellular Materials - Slab, Bonded, and Molded Urethane Foams
ASTM D3617	Practice for Sampling and Analysis of New Built-Up Roof Membranes
ASTM D3672	Venting Asphalt-Saturated and Coated Inorganic Felt Base Sheet Used in Roofing
ASTM D3817	Practice for Sampling and Analysis of New Built-Up Roof Membranes
ASTM D3909	Asphalt Roll Roofing (Glass Felt) Surfaced with Mineral Granules
ASTM D4012	Glass Fiber Reinforces Underground Storage Tanks
ASTM D4022	Coal-Tar Roof Cement
ASTM D41	Asphalt Primer Used in Roofing, Dampproofing and Waterproofing
ASTM D43	Creosote Primer Used in Roofing, Dampproofing and Waterproofing
ASTM D4434	Polyvinyl Chloride Sheets
ASTM D4479	Asphalt Roof Coatings - Asbestos Free
ASTM D449	Specification for Standard Sizes of Coarse Aggregate for Highway Construction
ASTM D450	Coal-Tar Pitch Used in Roofing, Dampproofing and Waterproofing
ASTM D4586	Asphalt Roof Cement - Asbestos Free
ASTM D4601	Asphalt-Coated Glass Fiber Base Sheet Used in Roofing
ASTM D75	Methods of Sampling Aggregates
ASTM D836	Fluid Applied Elastomer
ASTM D859	Tests for Silica in Water and Waste Water
ASTM D96	Calcium Chloride
ASTM D98	Specification for Calcium Chloride
ASTM DI335	Test Method for Tuft Bind of Pile Floor Coverings
ASTM E11	Specification for Wire Cloth Sieves for Testing Purposes
ASTM E119	Method for Fire Tests of Building Construction and Materials
ASTM E1190	Test Methods for Strength of Powder Actuated Fasteners Installed in Structural Members
ASTM E1264	Classification for Acoustical Ceiling Products
ASTM E283	Rate of Air Leakage Through Exterior Windows, Curtain Walls, and Doors
ASTM E330	Structural Performance of Exterior Windows, Curtain Walls, and Doors by Uniform Static Air Pressure Difference
ASTM E331	Water Penetration of Exterior Windows, Curtain Walls, and Doors by Uniform Static Air Pressure Difference

Standard	Title of Standard
ASTM E480	Test Method for Strength of Anchors in Concrete and Masonry Elements
ASTM E514	Water Penetration and Leakage Through Masonry
ASTM E514	Water Penetration and Leakage Through Masonry
ASTM E515	Leaks Using Bubble Emission Techniques
ASTM E515	Leaks Using Bubble Emission Techniques
ASTM E590	Practice for Application of Ceiling Suspension Systems for Acoustical Tile and Lay-In Panels in Areas Requiring Seismic Restraint
ASTM E64	Test Method for Surface Burning Characteristics of Building Materials
ASTM E648	Test Method for Critical Radiant Flux of Floor Covering Systems Using a Radiant Heat Energy Source
ASTM E662	Test Method for Specific Optical Density of Smoke Generated by Solid Materials
ASTM E737	Installation of Storm Windows, Replacement Windows, Multi-Glazing, Storm Doors, and Replacement Doors
ASTM E737	Installation of Storm Windows, Replacement Windows, Multi-Glazing, Storm Doors, and Replacement Doors
ASTM E795	Practices for Mounting Test Specimens During Sound Absorption Tests

C.3.13American Society of Heating, Refrigeration, and Air Conditioning Engineers (ASHRAE)

Standard	Title of Standard
ASHRAE 100	Energy Conservation in Existing Buildings
ASHRAE 15	Safety Code for Mechanical Refrigeration
ASHRAE 20	Methods of Testing for Rating Remote Mechanical Draft Air Cooled Refrigerant Condensers
ASHRAE 24	Methods of Testing For Rating Liquid Coolers
ASHRAE 3	Guidelines to Reduce CFC Refrigerant Emissions
ASHRAE 33	Methods of Testing Forced Circulation Air Cooling and Heating Coils
ASHRAE 51	Methods of Testing Fans for Rating
ASHRAE 52	Method of Testing Air-Cleaning Devices Used in General Ventilation for Removing Particulate Matter
ASHRAE 62	Ventilation for Acceptable Indoor Air Quality
ASHRAE 64	Methods of Testing Remote Mechanical Draft Evaporative Refrigerant Condensers
ASHRAE 70	Method of Testing for Rating the Air Flow Performance of Outlets and Inlets
ASHRAE 90A	Energy Conservation in New Building Design

C.3.14 American Society of Mechanical Engineers (ASME)

Standard	Title of Standard
ASME	Boiler and Pressure Vessel Code
ASME A17.1	Elevators and Escalators
ASME B16	Fittings Flanges and Valves
ASME B16.1	Cast-Iron Pipe Flanges
ASME B16.11	Forged-Steel Pipe Fittings
ASME B16.22	Copper Tube Fittings
ASME B16.3	Malleable-Iron Pipe Fittings
ASME B16.39	Malleable-Iron Pipe Unions
ASME B16.5	Steel Pipe Flanges
ASME B16.9	Wrought-Steel Pipe Fittings
ASME B31.1	Power Piping
ASME B31.9	Building Services Piping
ASME CSD-1	Controls and Safety Devices for Automatically Fired Boilers
ASME MH 141	American National Standard Loading Dock Levelers and Dockboards
ASME PIC4.1	Steam Generating Units

C.3.15American Welding Society (AWS)

Standard	Title of Standard
AWS 03	Welding Handbook
AWS A5.8	Brazing Welding Code – Steel
AWS A3.0	Standard Welding Terms and Definitions
AWS D1.1	Structural Welding Code - Steel
AWS D1.2	Structural Welding Code – Aluminum
AWS D1.3	Structural Welding Code - Sheet Steel
AWS D1.4	Structural Welding Code - Reinforcing Steel
AWS D5.2	Standards for Welded Steel, Elevated Tanks, Standpipes and Reservoirs for Water Storage
AWS D9.1	Sheet Metal Welding Code

C.3.16American Wood-Preservers' Association (AWPA)

Standard	Title of Standard
AWPA C1	All Timber Products - Preservative Treatment by Pressure Processes
AWPA C20	Structural Lumber - Fire-Retardant Treatment by Pressure Processes
AWPA C3-97	Piles - Preservative Treatment by Pressure Process
AWPA M2	Inspection of Treated Timber Products
AWPA M4	Care of Preservative - Treated Wood Products
AWPA Y4-94	Care of Pressure Treated Wood Products

C.3.17 Brick Institute of America (BIA)

Standard	Title of Standard
BIA Tech Note 20	Cleaning Brick Masonry

C.3.18 Building Officials and Code Administrators International (BOCA)

Standard	Title of Standard
BOCA 90	The BOCA National Plumbing Code

C.3.19 Concrete Reinforcing Steel Institute (CRSI)

Standard	Title of Standard
CRSI	Specifications for Placing Reinforcement
CRSI DA4	Manual of Standard Practice

C.3.20 Door and Hardware Institute (DHI)

Standard	Title of Standard
DHI 02	Installation Guide for Doors and Hardware
DHI 06	Basic Architectural Hardware
DHI A115	Steel Door Preparation Standards - Complete Set (Includes A115.1 through A115.7 and A115.12 through A115.17)
DHI A115.7	Preparation for Floor Closers - Light Duty, Center Hung, Single or Double Acting; Center Hung, Single or Double Hung; Offset Hung, Single Acting

C.3.21 Exterior Insulation Manufacturers Association (EIMA)

Standard	Title of Standard
EIMA 01	EIMA Guideline Specification for Exterior Insulation and Finish Systems Class PB Type A

C.3.22 Flat Glass Marketing Association (FGMA)

Standard	Title of Standard
FGYA 01-90	Glazing Manual
GA 201	Using Gypsum Board for Walls and Ceilings
GA 216	Recommended Specifications for the Application and Finishing of Gypsum Board
GA 219	Recommendations for Installation of Steel Fire Door Frames in Steel Stud - Gypsum Board Fire-Rated Partitions
GA 220	Special Recommendations - Gypsum Board Winter Related Problems
GA 505	Gypsum Board Products - Glossary of Terminology
GA 600	Fire Resistance Design Manual Eleventh Edition
GA 650	Recommendations for Covering Existing Interior Walls and Ceilings with Gypsum Board

C.3.23 Gypsum Association (GA)

Standard	Title of Standard
FGMA 01-90	Glazing Manual

C.3.24 Institute of Electrical and Electronic Engineers (IEEE)

Standard	Title of Standard
IEEE 112	Test Method B for Motor Efficiency

C.3.25 National Association of Architectural Metal Manufacturers (NAAMM)

Standard	Title of Standard
1988 Edition	Metal Finishes Manual for Architectural and Metal Products
NAAMM HMMA 802	Manufacturing of Hollow Metal Doors and Frames
NAAMM HMMA 830	Hollow Metal Manual; Section: Hardware Preparation and Locations for Hollow Metal Doors and Frames
NAAMM HMMA 840	Hollow Metal Manual; Section: Installation and Storage of Hollow Metal Doors and Frames
NAAMM HMMA 881	Hollow Metal Manual; Section: Guide Specifications for Commercial Hollow Metal Doors and Frames
NAAMM HMMA 862	Hollow Metal Manual; Section: Guide Specifications for Commercial Security Hollow Metal Doors and Frames

C.3.26 National Association of Garage Door Manufacturers (NAGDM)

Standard	Title of Standard
NAGDM 102	Specifications for Sectional Overhead Type Doors

C.3.27 National Association of Plumbing/Heating/Cooling Contractors (NAPHCC)

Standard	Title of Standard
NSPC	National Standard Plumbing Code

C.3.28 National Fire Protection Association (NFPA)

Standard	Title of Standard
NFPA 11	Low Expansion Foam and Combined Agent Systems
NFPA 12	Carbon Dioxide Extinguishing Systems
NFPA 12a	Halon 301 Fire Extinguishing Systems
NFPA 12b	Halon 1211 Fire Extinguishing Systems
NFPA 13	Standard for Installation of Sprinkler System.
NFPA 13A	Inspection, Testing and Maintenance of Sprinkler System
NFPA 14	Standard for Installation of Standpipe and Hose System
NFPA 15	Water Spray Fixed Systems for Fire Protection Extinguishing Systems

Standard	Title of Standard
NFPA 16	Installation of Deluge Foam Water Sprinkler and Foam-Water Spray Systems
NFPA 1662	Standard for Care, Use and Maintenance of Fire Hose
NFPA 1663	Fire Hose Connections; Screw Threads and Gaskets
NFPA 16a	Installation of Closed Head Foam Water Sprinkler Systems
NFPA 17	Dry Chemical Extinguishing Systems
NFPA 20	Standard for the Installation of Centrifugal Fire Pumps.
NFPA 211	Standard for Chimneys, Fireplaces, Vents and Solid Fuel Burning Appliances
NFPA 22	Standard for Water Tanks for Private Fire Protection
NFPA 231	Standard for General Storage
NFPA 24	Standard for Installation of Fire Service Mains and Their Appurtenances
NFPA 26	Recommended Practices for the Supervision of Valves Controlling Water Supplies for Fire Protection
NFPA 30	Flammable and Combustible Liquids Code
NFPA 31	Oil Burning Equipment
NFPA 37	Standard for the Installation and use of Stationary Combustion Engines and Gas Turbines
NFPA 46	Fire Protection for Laboratories Using Chemicals
NFPA 50A	Gaseous Hydrogen Systems
NFPA 56F	Test Medical Gas Piping, Including Pressure, Cross Connection, and Final Testing
NFPA 60	Oxygen Systems, Bulk
NFPA 60B	Liquefied Hydrogen Systems
NFPA 64	National Fuel Gas Code
NFPA 66	Storage and Handling of Liquid Petroleum Gas
NFPA 68	Explosion Venting
NFPA 70	National Electrical Code
NFPA 71	Standard for Installation, Maintenance and Use of Signaling Systems
NFPA 72	Protective Signaling System
NFPA 72E	Automatic Fire Detectors
NFPA 85A	Prevention of Furnace Explosions in Fuel Oil and Natural Gas Fired Single Burner Boiler Furnaces
NFPA 85B	Prevention of Furnace Explosions in Natural Gas Fired Multiple Burner Boiler Furnaces
NFPA 85D	Prevention of Furnace Explosions in Fuel Oil Fired Multiple Burner Boiler Furnaces
NFPA 85E	Prevention of Furnace Explosions in Pulverized Coal Fired Multiple Burner Boiler Furnaces
NFPA 85F	Installation and Operation of Pulverized Fuel Systems
NFPA 90A	Standard for the Installation of Air Conditioning and Ventilating Systems
NFPA 90B	Standard for the Installation of Warm Air Heating and Air Conditioning Systems

C.3.29 National Forest Products Association (NFPA)

Standard	Title of Standard
NFOPA 02	Manual for Wood Frame Construction

C.3.30 National Hardwood Lumber Association (NHLA)

Standard	Title of Standard
NHLA 01	Rules for the Measurement and Inspection of Hardwood and Cypress

C.3.31 National Oak Flooring Manufacturers Association (NOFMA)

Standard	Title of Standard
NOFMA	Hardwood Flooring Installation Manual
NOFMA	Hardwood Flooring Finishing/Refinishing Manual
NOFMA	Behavior of Floors

C.3.32 National Terrazzo and Mosaic Association, Inc. (NTMA)

Standard	Title of Standard
NTMA	Terrazzo Technical Design
NTMA	Terrazzo Design Data

C.3.33 National Wood Windows and Door Association (NWWDA)

Standard	Title of Standard
NWWDA IS 1	Wood Flush Doors
NWWDA IS 2	Wood Windows
NWWDA IS 4	Water-Repellent Preservative Treatment for Millwork

C.3.34 Plumbing and Drainage Institute (PDI)

Standard	Title of Standard
PDI G101	Testing and Related Procedure for Grease Interceptors

C.3.35 Portland Cement Association (PCA)

Standard	Title of Standard
PCA	Specification for Plain and Reinforced Concrete
PCA	Architectural Concrete Specifications

C.3.36 Precast/Prestressed Concrete Institute (PCI)

Standard	Title of Standard
PCI MnI-116	Manual for Quality Control for Plants and Production of Precast and Prestressed Concrete Products
PCI MnI-120	PCI Design Handbook – Precast and Prestressed Concrete

C.3.37 Sheet Metal and Air Conditioning Contractors Association (SMACNA)

Standard	Title of Standard
1987 Edition	Architectural Sheet Metal Manual
AFDS-100-73	Pressure Sensitive Tape

C.3.38 Society for Protective Coatings (SSPC)

Standard	Title of Standard
SSPC PA-1	Shop, Field, and Maintenance Painting
SSPC PA-12	Paint Specification No. 12 – Cold-Applied Asphalt Mastic (Extra Thick Film)
SSPC PA-20	Paint Specification No. 20 – Zinc-Rich Primers (Type I, “Inorganic,” and Type II, “Organic”)

C.3.39 Steel Door Institute (SDI)

Standard	Title of Standard
SD01 SDI 100	Standard Steel Doors and Frames
SD01 SDI 105	Recommended Erection Instructions for Steel Frames
SD01 SDI 106	Standard Door Type Nomenclature
SD01 SDI 107	Hardware on Steel Doors
SD01 SDI 111	Recommended Standard Details, - Steel Doors and Frames

C.3.40 Truss Plate Institute (TPI)

Standard	Title of Standard
TPI TPI	Design Specification for Metal Plate Connected Wood Trusses
TPI QST	Quality Standard for Metal Plate Connected Wood Trusses Addendum to TPI-85
TPI BWl	Bracing Wood Trusses

C.3.41 Underwriters Laboratories, Inc. (UL)

Standard	Title of Standard
UL 1247	Fire Pump Diesel Engine Driver
UL 1261	Electric Water Heaters for Pools and Tubs
UL 1453	Electric Booster and Commercial Storage Tank Water Heaters
UL 1476	Relief valves
UL 1479	Fire Test of Through Penetration Fire Stops
UL 174	Household Electric Storage Tank Water Heaters
UL 207	Refrigerant Containing Components and Accessories
UL 343	Standard for Pumps for Oil-Burning Appliances
UL 443	Steel Auxiliary Tanks for Oil-Burner Fuel
UL 448	Fire Pumps
UL 485	Central Cooling Air Conditioners

Standard	Title of Standard
UL 56	Steel Underground Tanks for Flammable and Combustible Liquids
UL 586	Industrial Control Equipment
UL 587	Pipe Connections for Flammable and Combustible Liquids and LP-Gas
UL 588	High Efficiency, Particulate, Air-Filter Units
UL 705	Power Ventilators - Design, Manufacture, and Testing
UL 731	Oil-Fired Unit Heaters
UL 732	Oil Fired Water Heaters
UL 778	Motor Operated Water Pumps
UL 80	Standard for Steel Inside Tanks for Oil-Burner Fuel
UL 834	Heating, Water Supply, and Power Boilers - Electric
UL 883	Safety Standards for Fan Coil Units and Room Fan Heater Units
UL 900	Test Performance of Air Filter Units
UL 959	Refractory Lining Testing for Temperature and Acid Resistance
UL 98	Steel Underground Tanks for Flammable and Combustible Liquids
UL 984	Hermetic Refrigerant Motor Compressors
UL MH 1316	Standard for Glass-Fiber Reinforced Plastic Underground Storage Tanks for Petroleum Products
UL MH 1316	Standard for Glass-Fiber Reinforced Plastic Underground Storage Tanks for Petroleum Products

C.3.42 Uniform Building Code (UBC)

Standard	Title of Standard
UBC	The UBC National Building Code

C.4 Industry Publications

Publication	Publisher
1991 ASTM Standards in Building Codes	American Society for Testing and Materials 1916 Race St. Philadelphia, PA 19103
ACI Detailing Manual and Structural Concrete for Buildings	American Concrete Institute P.O. Box 19150 Detroit, MI 48219-0150
Electrical Protection Handbook	Bussman, Cooper Industries P.O. Box 41460 St. Louis, MO 63178
Fences by Anchor Vehicle Gate Operators	Anchor Fence, Inc. 6500 Eastern Ave. Baltimore, MD 21224
Fibrous Glass Duct Construction Standard, 5th Ed., 1979. SMACNA Fire, Smoke and Radiation Damper Installation Guide for HVAC Systems, 3rd Ed., 1988. SMACNA	Sheet Metal and Air Conditioning Contractors National Association P.O. Box 70 Merrifield, VA 22116

Publication	Publisher
HVAC Air Duct Leakage Test Manual, 1st Ed., 1988. SMACNA HVAC Duct Construction Standards Metal and Flexible, 1st Ed., 1988. SMACNA HVAC System-Testing, Adjusting and Balancing, 1st Ed., 1988. SYACNA Retrofit of Building Systems and Processes, 1st Ed. 1982. SYACNA	
Field Inspection Guide	Chain Link Fence Manufacturer's Institute
FM Approval Guide and FM Loss Prevention Data Sheets	Factory Mutual Research Norwood, MA 02062
Handbook for Ceramic Tile Installation	Tile Council of America 10233 Sandyville Rd., SE East Sparta, OH 44626
Index of Federal Specifications, Standards and Commercial Item Descriptions	General Services Administration Office of Federal Supply and Services 7th and D Streets SW Washington, DC 20202
Landscape Design for Sun and Wind Control	American Institute of Nurserymen 200 Southern Building Washington, D.C. 20005
Masterspec	American Institute of Architects 1735 New York Ave. NW Washington, D.C. 20006
National Fire Protection Association	National Electrical Code NFPA 70, 1990 Edition Recommended Practice for Electrical Equipment Maintenance NFPA 70B, 1990 edition
On the Fence About Fencing	Chain Link Fence Manufacturer's Institute 1776 Massachusetts Ave. NW Washington, D.C. 20036
Putting Drywall in a More Critical Light, 1987	USG Interiors, Inc. 101 South Wacker Dr. Chicago, IL 60606
Terminology, Design, Hardware, Engineering Specifications	Aluminum Store Front and Entrance Manual 2700 River Rd. Des Plaines, IL 60018
Terrazzo Design Data	National Terrazzo and Mosaic Association, Inc. 3166 Des Plaines Ave., Suite 132 Des Plaines, IL 60018
The NRCA Roofing and Waterproofing Manual	National Roofing Contractors Association 6250 River Rd. Rosemont, IL 60018
UL Building Materials Directory UL Directory of General Information for Electrical Construction, Hazardous Location, and Electric Heating and Air-Conditioning Equipment	Underwriters Laboratories, Inc. 333 Pfingsten Rd. Northbrook, IL 60062
Westinghouse Maintenance Hints	HB 6001-R

D
LISTING OF KEY INFORMATION

D.1 Key O&M Cost Points



Key O&M Cost Point

Emphasizes information that results in reduced purchase, operating, or maintenance costs.

Referenced Section	Page Number	Key Point
4.4.2.1	4-37	A major source of trouble in duct systems, often resulting in the complete unbalancing of the system, is tampering with dampers and grills by unauthorized persons.
7.1	7-1	As a general rule of thumb, if the repair costs 50% or less than the replacement cost, then repair should be considered feasible. If the percentage is greater, then replacement is generally the best option.
7.2.2.2	7-9	It is often useful to know the expected lifetime of the component under consideration when deciding whether to replace or repair it.

D.2 Key Technical Points



Key Technical Point

Targets information that leads to improved equipment reliability.

Referenced Section	Page Number	Key Point
3.1.1	3-1	Loads are applied to a structure or building element in two ways: either as a distributed load or a concentrated (point) load.
3.1.3	3-2	Two basic types of forces—tension and compression— (and thus induced stress) cause material deterioration.
3.3.4	3-13	The most common types of roof failure are splits in the roofing, moisture impregnation, improper drainage, and material degradation or deterioration.
3.3.5	3-15	Typical failure mechanisms for windows include surface (frame) disintegration, swelling and warping of the frame (causing binding or loss of seal), loose or broken hardware, corrosion or rusting of metal frames and hardware, deteriorated or disintegrated weather stripping, or broken glass.

Referenced Section	Page Number	Key Point
3.3.6.1	3-16	Paints that are exposed to the external environment normally proceed through two stages of deterioration: generally, a change in appearance followed by gradual degradation.
3.4.3.3	3-29	The most common cause of motor failure is contamination.
4.2.1.1	4-3	The most important tool in determining types of deterioration in concrete is visual inspection.
4.2.2.1	4-7	As with any structural-type members, not only should the members be inspected, but also their connections to other members.
4.3.4.1	4-22	Inspection criteria that are common to all types of roofs are checking the general appearance of the roof surface, looking for any evidence of mechanical damage to the roofing system, and checking the water tightness of the roofing system.
4.3.6	4-31	The most effective way to conduct a thorough coatings condition assessment and detect coating degradation is through visual inspection.

D.3 Key Human Performance Points



Key Human Performance Point

Denotes information that requires personnel action or consideration in order to prevent injury or damage or to ease completion of the task.

Referenced Section	Page Number	Key Human Performance Points
2.3.2.3	2-11	Some older tiles contain asbestos, which requires special measures for personnel protection and the implementation of numerous environmental regulations and statutes upon their removal.
2.3.2.6	2-15	Some older paints contain PCBs for fire retardancy, which require special measures for personnel protection and the implementation of numerous environmental regulations and statutes upon their removal.
A.1.1	A-1	It is incumbent upon each facility maintenance manager to understand the boundaries of responsibility regarding the routine maintenance of SSCs at each particular site.

E
TRANSLATED TABLE OF CONTENTS

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ORGANIZATION(S) THAT PREPARED THIS DOCUMENT

EPRI

RESUME

Objectifs

- Pour aider jusque dans le détail le personnel des centrales nucléaires et des installations nucléaires du département de l’énergie américain, chargé de la maintenance des bâtiments administratifs et des installations
- Pour fournir des conseils concernant les mécanismes de dégradation des différentes parties des bâtiments et composants d’installations
- Pour fournir des informations permettant de définir l’état de référence à partir duquel l’installation ou le bâtiment sera évalué
- Pour fournir des techniques d’inspection et des informations pour leur mise en œuvre efficace
- Pour fournir des conseils pour faire de l'entretien préventif et les réparations

TABLE DES MATIERES

1 **INTRODUCTION 1-1**

1.1 Historique 1-1

1.2 Objectif 1-1

1.3 Portée 1-2

1.3.1 Gamme d'installations et composants d'installations décrits dans ce rapport 1-2

1.3.2 But et organisation de ce rapport 1-3

1.4 Intégration des conseils dans ce rapport 1-3

1.5 Utilisation efficace des conseils dans ce rapport 1-4

1.6 Acronymes 1-5

1.7 Points clés 1-7

1.8 Conversions d'unité 1-9

2 **VUE D'ENSEMBLE DE L'ENTRETIEN DES INSTALLATIONS 2-1**

2.1 Types d'entretien 2-1

2.2 Types de forces agissant sur les installations 2-2

2.3 But et types de composants de bâtiment 2-3

2.3.1 Composants Structuraux Principaux 2-3

2.3.1.1 Béton armé 2-3

2.3.1.2 Acier de construction 2-4

2.3.1.3 Wood/Timber Bois/Poutres 2-4

2.3.2 Matériaux de finition 2-5

2.3.2.1 Matériaux pour l'extérieurs 2-5

2.3.2.2 Matériaux intérieurs pour plafonds et murs 2-5

2.3.2.3 Planchers 2-9

2.3.2.4 Toits 2-12

2.3.2.5 Fenêtres et portes 2-14

2.3.2.6 Enduits pour les surfaces extérieures 2-15

2.3.3 Circuits des installations 2-19
2.3.3.1 Circuits de distribution d'Eau 2-20
2.3.3.2 Circuits de chauffage, ventilation, et de climatisation 2-20
2.3.3.3 Circuits Électriques 2-20
2.3.3.4 Systèmes de transfert 2-22
2.3.4 Circuits Externes 2-22
2.3.4.1 Allées, routes, trottoirs et surfaces revêtues d'asphalte 2-22
2.3.4.2 Circuits d'écoulement, de drainage, et de maîtrise de l'érosion 2-23
2.3.4.3 Clôtures 2-24
2.3.4.4 Réservoirs 2-25
2.4 Avantages et inconvénients de divers matériaux de construction 2-25

3 MÉCANISMES DE DÉGRADATION ET MODES DE VIEILLISSEMENT 3-1
3.1 Introduction 3-1
3.1.1 Types de chargement 3-1
3.1.2 Déformation et contrainte 3-1
3.1.3 Tension et compression 3-2
3.1.4 Types de contrainte 3-2
3.2 Mécanismes de dégradation des principaux matériaux structuraux 3-3
3.2.1 Béton armé 3-3
3.2.2 Acier De Construction 3-6
3.2.3 Bois/Poutres 3-7
3.3 Mécanismes de dégradation des matériaux de finition 3-10
3.3.1 Matériaux pour l'xtérieur 3-10
3.3.1.1 Extérieurs en bois 3-10
3.3.1.2 Extérieurs en métal 3-10
3.3.1.3 Maçonnerie et extérieurs en béton 3-10
3.3.1.4 Extérieurs revêtus minéral 3-10
3.3.2 Matériaux intérieurs pour plafonds et murs 3-10
3.3.3 Planchers 3-12
3.3.4 Toits 3-13
3.3.5 Fenêtres et portes 3-15
3.3.6 Enduits pour les surfaces extérieures 3-16
3.3.6.1 Détérioration extérieure 3-16
3.3.6.2 Désintégration 3-17

3.3.6.3 Détérioration complète....3-17
3.4 Mécanismes de dégradation des circuits des installations 3-18
3.4.1 Circuits de distribution de l'Eau 3-18
3.4.1.1 Plomberie pour eau d'alimentation et eaux usées 3-18
3.4.1.2 Circuits de protection contre les incendies 3-20
3.4.2 Circuits de chauffage, ventilation, et de climatisation 3-20
3.4.2.1 Circuit de ventilation et d'extraction d'air des installations et bâtiments 3-20
3.4.2.2 Circuits de chauffage des bâtiments 3-22
3.4.2.3 Circuits pneumatiques 3-24
3.4.2.4 Circuits de climatisation 3-25
3.4.3 Circuits électriques 3-27
3.4.3.1 Circuits électriques de distribution 3-27
3.4.3.2 Circuits d'éclairage 3-28
3.4.3.3 Moteurs 3-28
3.4.3.4 Batteries 3-29
3.4.3.5 Transformateurs 3-29
3.4.3.6 Systèmes d'alarme et d'interphone 3-29
3.4.4 Systèmes de transfert....3-29
3.4.4.1 Ascenseurs Hydrauliques 3-29
3.4.4.2 Ascenseurs mécaniques 3-30
3.4.4.3 Escaliers mécaniques 3-30
3.5 Mécanismes de dégradation des circuits externes 3-30
3.5.1 Allées, routes, trottoirs et surfaces revêtues d'asphalte 3-30
3.5.2 Circuits d'écoulement, de drainage, et de maitrise de l'érosion 3-31
3.5.2.1 Érosion par le vent 3-31
3.5.2.2 Érosion par l'eau 3-31
3.5.2.3 Mécanismes de dégradation des circuits de drainage et de maitrise de l'érosion 3-31
3.5.3 Clôtures 3-31
3.5.4 Réservoirs 3-32
3.6 Réparation des dégradations 3-32
3.7 Estimation de la durée de vie de conception 3-32

4 SURVEILLANCE CONDITIONNELLE 4-1
4.1 Introduction 4-1

4.1.1 Conseils Généraux pour l'Inspection des installations 4-1
4.1.2 Fréquences d'Inspection recommandées 4-2
4.2 Inspection des principaux matériaux structuraux 4-3
4.2.1 Béton armé 4-3
4.2.1.1 Critères d'Inspection généraux 4-3
4.2.1.2 Critères d'inspection pour les dalles 4-5
4.2.1.3 Critères d'inspection pour les poutres et les poteaux coulés sur place 4-6
4.2.1.4 Critères d'inspection pour les poutres précontraintes enbéton préfabriqué 4-6
4.2.2 Acier de construction 4-7
4.2.2.1 Critères d'Inspection généraux 4-7
4.2.2.2 Critères d'inspection pour les poutres et les poteaux en acier 4-8
4.2.2.3 Critères d'inspection pour les structures en acier des bâtiments prêtes à monter 4-9
4.2.3 Bois/Poutres 4-10
4.2.3.1 Critères d'Inspection généraux 4-10
4.2.3.2 Affaissement 4-11
4.2.3.3 Taros 4-11
4.2.3.4 Insectes 4-11
4.2.3.5 Critères d'inspection pour les poutres et les poteaux en bois 4-12
4.2.3.6 Critères d'inspection pour les structures en bois préfabriquées 4-13
4.2.3.7 Critères d'inspection pour l'ignifuge de poteaux 4-13
4.3 Inspection des matériaux de finition des installations 4-14
4.3.1 Matériaux extérieurs 4-14
4.3.1.1 Extérieurs en bois 4-14
4.3.1.2 Extérieurs en métal 4-14
4.3.1.3 Maçonnerie et extérieurs en béton 4-15
4.3.1.4 Extérieurs revêtus minéral 4-15
4.3.2 Matériaux intérieurs pour plafonds et murs 4-16
4.3.2.1 Critères d'inspection généraux 4-16
4.3.2.2 Critères d'inspection pour les cloisons conventionnelles 4-16
4.3.2.3 Les critères d'inspection pour les cloisons spéciales 4-17
4.3.2.4 Les critères d'inspection pour les cloisosns des toilettes 4-17
4.3.2.5 Critères d'inspection pour les revêtements muraux 4-17
4.3.2.6 Critères d'inspection pour les plafonds 4-18

4.3.3 Planchers et escaliers 4-18
4.3.3.1 Critères d'inspection pour les planchers en béton coulé sur place 4-19
4.3.3.2 Les critères d'inspection pour les planchers en béton préfabriqué 4-19
4.3.3.3 Critères d'inspection pour les planchers en acier 4-20
4.3.3.4 Critères d'inspection pour les planchers en matériaux composites 4-20
4.3.3.5 Critères d'inspection pour les planchers en bois 4-21
4.3.3.6 Critères d'inspection pour les revêtements de sol 4-22
4.3.4 Toits 4-22
4.3.4.1 Critères d'Inspection généraux 4-22
4.3.4.2 Critères d'inspection pour les charpentes de toit en béton 4-23
4.3.4.3 Critères d'inspection pour les charpentes de toit en acier 4-23
4.3.4.4 Critères d'inspection pour les charpentes de toit en bois 4-24
4.3.4.5 Critères d'inspection pour les toits constitués d’une membrane 4-25
4.3.4.6 Les critères d'inspection pour les toits constitués d’une membrane à simple pli 4-25
4.3.4.7 Critères d'inspection pour les toitures en métal 4-26
4.3.4.8 Critères d'inspection pour les toits constitués d’une mousse revêtue e 4-26
4.3.4.9 Critères d'inspection pour les toits de bardeau bituminé 4-27
4.3.4.10 Critères d'inspection pour les toits de tuile 4-27
4.3.4.11 Critères d'inspection pour les parapets 4-28
4.3.4.12 Critères d'inspection pour les gouttières 4-28
4.3.4.13 Critères d'inspection pour les particularités des toits 4-29
4.3.4.14 Critères d'inspection pour les lucarnes 4-29
4.3.5 Fenêtres et portes 4-30
4.3.5.1 Critères d'inspection pour les fenêtres 4-30
4.3.5.2 Critères d'inspection pour les portes intérieures 4-31
4.3.6 Enduits des surfaces extérieures 4-31
4.4 Inspection des circuits des installations 4-32
4.4.1 Circuits de distribution d'eau 4-32
4.4.1.1 Plomberie pour eau d’alimentation et eaux usées 4-32
4.4.1.2 Circuits de protection contre l’incendie 4-34
4.4.1.3 Toilettes et accessoires 4-35
4.4.1.4 Éjecteurs d'eaux usées 4-35
4.4.1.5 Réservoirs de stockage 4-36
4.4.1.6 Réservoirs et puisards 4-36

4.4.1.7 Conditionneurs d'eau 4-37
4.4.2 Chauffage, ventilation, et climatisation 4-37
4.4.2.1 Gaines et circuits de ventilation 4-37
4.4.2.2 Circuits de chauffage 4-39
4.4.2.3 Chauffes-eau 4-42
4.4.2.4 Circuits pneumatiques 4-43
4.4.2.5 Circuits de distribution de vapeur 4-50
4.4.2.6 Circuits de distribution d'eau à haute température 4-51
4.4.2.7 Instrumentation et commandes 4-52
4.4.2.8 Climatisation 4-53
4.4.3 Circuits électriques 4-55
4.4.3.1 Circuits électriques de distribution 4-55
4.4.3.2 Circuits d'éclairage 4-57
4.4.3.3 Moteurs 4-59
4.4.3.4 Batteries 4-61
4.4.3.5 Transformateurs 4-62
4.4.3.6 Alarme et interphone 4-64
4.4.4 Systèmes de transfert....4-65
4.4.4.1 Ascenseurs Hydrauliques 4-65
4.4.4.2 Ascenseurs mécaniques 4-65
4.4.4.3 Escaliers mécaniques 4-66
4.5 Inspection des circuits externes 4-66
4.5.1 Allées, routes, trottoirs et surfaces revêtues d’asphalte 4-66
4.5.2 Écoulement, drainage et circuit de maitrise de l’érosion 4-66
4.5.3 Clôtures 4-66
4.5.4 Réservoirs 4-67

5 MAINTENANCE PRÉVENTIVE ET ANTICIPATRICE 5-1
5.1 Entretien courant pour les principaux matériaux structuraux 5-1
5.1.1 Béton armé 5-1
5.1.1.1 Prévention de la détérioration 5-1
5.1.1.2 Entretien courant 5-2
5.1.1.3 Enduits 5-3
5.1.1.4 Détachage 5-4
5.1.2 Acier de construction 5-5

5.1.2.1 Prévention de la détérioration 5-5
5.1.2.2 Entretien courant 5-7
5.1.3 Bois/poutres 5-8
5.1.3.1 Arrêter l'affaissement t des éléments en bois 5-8
5.1.3.2 Prévention de l’attaque par les termites 5-8
5.1.3.3 Traitement contre les termites 5-9
5.1.3.4 Mesures Préventives 5-9
5.1.3.5 Traitements du bois 5-10
5.2 Entretien des matériaux de finition des installations 5-11
5.2.1 Matériaux extérieurs 5-11
5.2.1.1 Extérieurs en bois 5-11
5.2.1.2 Extérieurs en métal 5-11
5.2.1.3 Maçonnerie et extérieurs en béton 5-12
5.2.1.4 Extérieurs revêtus minéral 5-12
5.2.2 Matériaux intérieurs pour plafonds et murs 5-14
5.2.2.1 Plâtre 5-14
5.2.2.2 Murs secs 5-14
5.2.2.3 Carrelage 5-14
5.2.2.4 Carrelage acoustique 5-14
5.2.2.5 Bois 5-15
5.2.3 Planchers 5-15
5.2.3.1 Conseils généraux 5-15
5.2.3.2 Types d'entretien courant du plancher 5-16
5.2.3.3 Procédures d'entretien détaillées du plancher 5-16
5.2.4 Toits 5-19
5.2.4.1 Toits construits 5-19
5.2.4.2 Toits de bardeau bituminé 5-19
5.2.4.3 Toits en bitume roulé 5-19
5.2.4.4 Toits en bitume cimenté 5-20
5.2.4.5 Toits en métal 5-20
5.2.4.6 Toits d'ardoise 5-21
5.2.4.7 Toits en bois 5-21
5.2.4.8 Toits à simple-membrane 5-21
5.2.5 Fenêtres et portes 5-22
5.2.5.1 Fenêtres 5-22

5.2.5.2 Portes 5-22
5.2.6 Enduits pour les surfaces extérieures 5-23
5.3 Entretien courant des circuits des installations 5-24
5.3.1 Circuits de distribution d'eau 5-24
5.3.1.1 Plomberie pour eau d'alimentation et eau usées 5-24
5.3.1.2 Circuits de protection contre l' incendie 5-26
5.3.2 Circuits de chauffage, ventilation, et climatisation 5-26
5.3.2.1 Gaines et circuits de ventilation 5-27
5.3.2.2 Circuits de chauffage 5-27
5.3.2.3 Chauffes-eau 5-29
5.3.2.4 Circuits pneumatiques 5-30
5.3.2.5 Circuits de distribution de vapeur 5-32
5.3.2.6 Circuits de distribution d'eau à haute température 5-32
5.3.2.7 Instrumentation et commandes 5-32
5.3.2.8 Climatisation 5-33
5.3.3 Circuits électriques 5-35
5.3.3.1 Circuits de distribution d'électricité.....5-35
5.3.3.2 Circuits d'éclairage 5-36
5.3.3.3 Moteurs 5-38
5.3.3.4 Batteries 5-40
5.3.3.5 Transformateurs 5-41
5.3.3.6 Alarme et interphone 5-41
5.3.4 Systèmes de transfert.....5-41
5.4 Entretien courant des systèmes externes 5-42
5.4.1 Allées, routes, trottoirs et surfaces revêtues d'asphalte 5-42
5.4.2 Écoulement, drainage et circuit de maitrise de l'érosion 5-42
5.4.2.1 Circuits de drainage et de maitrise de l'érosion 5-42
5.4.2.2 Structures de drainage et de maitrise de l'érosion 5-42
5.4.3 Clôtures 5-45
5.4.4 Réservoirs 5-45

6 MAINTENANCE CORRECTIVE ET RÉPARATIONS 6-1
6.1 Réparation des principaux matériaux structuraux. 6-1
6.1.1 Réparation du béton armé 6-1
6.1.1.1 Considérations de pré-réparation 6-1

6.1.1.2 Réparation des fissures du béton 6-2
6.1.1.3 Réparation d'infiltrations d'eau 6-4
6.1.1.4 Résine thermodurcissable (époxy) 6-4
6.1.1.5 Traitement de la réparation 6-5
6.1.2 Réparation de l'acier de construction 6-5
6.1.2.1 Composants en acier de construction 6-5
6.1.2.2 Raccordements 6-6
6.1.2.3 Réparations spéciales de composants structuraux 6-7
6.1.3 Réparation des pièces de charpente en bois 6-8
6.1.3.1 Conseils généraux de réparation 6-8
6.1.3.2 Poutres en lamellé collé 6-9
6.2 Réparation des matériaux de finition des installations 6-9
6.2.1 Matériaux Extérieurs 6-9
6.2.1.1 Extérieurs en bois 6-9
6.2.1.2 Extérieurs en métal 6-9
6.2.1.3 Maçonnerie et extérieurs en béton 6-11
6.2.1.4 Extérieurs revêtus minéral 6-11
6.2.2 Matériaux intérieurs pour plafonds et murs 6-12
6.2.2.1 Plâtre 6-12
6.2.2.2 Murs secs 6-12
6.2.2.3 Carrelage 6-12
6.2.2.4 Carrelage acoustique 6-12
6.2.2.5 Bois 6-12
6.2.3 Planchers 6-13
6.2.3.1 Planchers Résilients 6-13
6.2.3.2 Dalles en béton 6-13
6.2.3.3 Planchers métalliques 6-13
6.2.3.4 Planchers sans joints 6-13
6.2.3.5 Planchers en bois 6-13
6.2.3.6 Moquette 6-14
6.2.4 Toits 6-14
6.2.4.1 Toits Construits 6-14
6.2.4.2 Toits en bardeau bituminé 6-16
6.2.4.3 Toits en bitume roulé 6-16
6.2.4.4 Toits en bitume cimenté 6-16

6.2.4.5 Toits en métal 6-16
6.2.4.6 Toits d'ardoise 6-17
6.2.4.7 Toits en bois 6-17
6.2.4.8 Toits à simple membrane 6-17
6.2.5 Fenêtres et portes 6-17
6.2.6 Enduits pour les surfaces extérieures 6-18
6.3 Réparation des circuits des installations 6-18
6.3.1 Circuits de distribution d'eau 6-18
6.3.1.1 Plomberie pour eau alimentaire et eaux usées 6-18
6.3.1.2 Circuit de protection incendie 6-18
6.3.2 Chauffage, ventilation, et climatisation 6-18
6.3.3 Circuits électriques 6-19
6.3.4 Systèmes de transfert 6-19
6.4 Réparation des circuits externes 6-19
6.4.1 Allées, routes, trottoirs et surfaces revêtues d’asphalte 6-19
6.4.2 Écoulement, drainage et circuit de maitrise de l’érosion 6-21
6.4.3 Clôtures 6-21
6.4.3.1 Raccordement 6-21
6.4.3.2 Remplacement des clôtures du type chaîne-lien 6-22
6.4.4 Réservoirs 6-22

7 GESTION DE L'ENTRETIEN DES INSTALLATIONS 7-1
7.1 Analyse des réparations, remplacements, et des ajournements 7-1
7.1.1 Facteurs à prendre en compte pour l’analyse complète 7-1
7.1.1.1 Facteurs quantificatifs pour l'étude de coût 7-2
7.1.1.2 Facteurs qualitatifs principaux dans le processus de décision 7-4
7.1.1.3 Aautres facteurs qualitatifs à prendre en compte 7-4
7.2 Processus de décision 7-6
7.2.1 Décision de réparer 7-7
7.2.2 Réparation de la détérioration 7-8
7.2.2.1 Choix d'un procédé de réparation 7-8
7.2.2.2 Considérations additionnelles pour la réparation 7-9
7.2.3 Report d'une réparation 7-9
7.2.4 Appel aux sous traitants et sous traiter les réparations 7-9
7.2.5 Évaluation de l'efficacité de la décision 7-10

7.3 Méthodes alternatives d'analyse 7-10
7.4 Problèmes de gestion de l'entretien d'autres installations 7-11
7.4.1 Coûts à long terme des installations 7-11
7.4.2 Accessibilité aux informations de conception et gestion de la configuration 7-11

***8* RÉFÉRENCES 8-1**
8.1 Références internes au texte 8-1
8.2 Bibliographie 8-1
8.3 Guides EPRI concernés supplémentaires 8-2
8.4 Organismes industriels et commerciaux 8-6

***A* ÉLEMENTS DE PROGRAMMATION CLESZ A-1**
A.1 Identification et catégorisation des installations A-1
A.1.1 Type fonctionnel de catégorisation A-1
A.1.2 Détermination de la propriété immobilière réelle A-1
A.2 Types et prioritization des activités d'entretien A-2
A.2.1 Introduction A-2
A.2.2 Entretien correctif A-2
A.2.3 Entretien préventif A-2
A.2.4 Entretien anticipatif A-3
A.2.5 Entretien conditionnel A-4
A.2.6 Report d'entretien A-4

***B* ESTIMATION DE LA DUREE DE VIE DE CONCEPTION B-1**
B.1 Fondations B-1
B.2 Sous-structures B-2
B.2.1 Dalles B-2
B.2.2 Poteaux B-2
B.3 Superstructures B-2
B.3.1 Dalles de plancher B-2
B.3.2 Escaliers B-3
B.3.3 Armature structurale B-3
B.3.4 Murs porteurs B-3
B.3.5 Dalles B-3
B.4 Huisseries extérieures B-4
B.5 Toiture B-5

B.6 Finitions intérieures et construction B-6
B.6.1 Murs B-6
B.6.2 Balustrades et mains courantes B-7
B.6.3 Murs, planchers, et plafonds B-7
B.7 Systèmes de transfert B-8
B.8 Systèmes Mécaniques B-8
B.8.1 Plomberie B-8
B.8.2 Équipements de protection contre l'incendie B-9
B.8.3 Chauffage, ventilation, et climatisation B-10
B.9 Systèmes mécaniques B-12
B.9.1 Service et distribution B-12
B.9.1.1 Basse tension B-12
B.9.1.2 Moyenne tension B-13
B.9.2 Eclairage B-13
B.9.3 Systèmes particuliers B-13
B.10 Systèmes spécialisés B-13
B.11 Travail sur site B-14
B.11.1 Pavage des chaussées et des trottoirs B-14
B.11.2 Tunnels B-14
B.11.3 Clôtures et portes de sécurité B-14
B.11.4 Ponts et butées B-14

C CODES ET NORMES C-1
C.1 But C-1
C.2 Spécifications fédérales C2
C.3 Normes Nationales C-8
C.3.1 Institut pour la climatisation et la réfrigération C-8
C.3.2 Association pour la circulation et la commande d'air C-8
C.3.3 Association des fabricants architecturaux Américains C-9
C.3.4 Association américaine des coloristes et des chimistes du textile C-9
C.3.5 Institut Américain du béton C-9
C.3.6 Association Américaine des panneaux durx C-10
C.3.7 Institut Américain de la construction en acier C-10
C.3.8 Institut Américain de la construction en de bois C-10
C.3.9 Institut Américain de la sidérurgique C-10

C.3.10 American National Standards Institute C-10
C.3.11 Association Américaine du contre-plaqué C-11
C.3.12 Société Américaine des essais et des matériaux C-11
C.3.13 Société Américaine des ingénieurs du chauffage, de la réfrigération, et de la climatisation C-18
C.3.14 Société Américaine des ingénieurs mécaniciens C-19
C.3.15 Société Américaine de soudure C-19
C.3.16 L'association Américaine pour la préservation du bois C-19
C.3.17 Institut Américain de la brique C-20
C.3.18 Bâtiment officiels et administrateurs de code internationaux C-20
C.3.19 Institut de l’armement du béton par l’acier C-20
C.3.20 Institut des portes et des huisseries C-20
C.3.21 Association des fabricants d'Isolation extérieure C-20
C.3.22 Association des promoteurs du verre plat C-20
C.3.23 Association du gypse C-21
C.3.24 Institut des ingénieurs électriques et électroniciens C-21
C.3.25 Association nationale des fabricants de métal pour l’architecture C-21
C.3.26 Association nationale des fabricants de porte de garage C-21
C.3.27 Association nationale des entrepreneurs de plomberie/chauffage/refroidissement C-21
C.3.28 Association nationale de protection contre les incendies C-21
C.3.29 Association nationale de produits Forestiers C-23
C.3.30 Association nationale des bois durs de charpente C-23
C.3.31 Association nationale des fabricants de planchers en chêne C-23
C.3.32 Association nationale de Terrazzo et de mosaïque, inc.. ..... C-23
C.3.33 Association nationale des fenêtres et portes en bois C-23
C.3.34 Institut de la plomberie et du drainage C-23
C.3.35 Association du ciment de Portland C-23
C.3.36 Institut du béton précontraint et préfabriqué C-23
C.3.37 Association des entrepreneurs en feuilles métalliques et en climatisation C-24
C.3.38 Société pour les enduits protecteurs C-24
C.3.39 Institut des portes en acier C-24
C.3.40 Institut des plaques renforcées C-24
C.3.41 Underwriters Laboratoires, Inc.. ..... C-24
C.3.42 Code des bâtiment homogènes C-25

C.4 Publications de lindustrie C-25

***D* LISTE DES INFORMATIONS CLÉS D-1**

D.1 Points clés d'organisation et de maintenance D-1

D.2 Points techniques clés D-1

D.3 Points clés de performance humaine D-2

LISTE DES FIGURES

1-1 Intégration des conseils de maintenance 1-4
2-1 Caractéristiques et informations sur les peintures et revêtements 2-17
4-1 Avantages et apports bénéfiques de l'examen visuel pour la détermination de l'état des revêtements 4-32
7-1 Facteurs à prendre en compte dans le processus de prise de décision 7-2
7-2 Processus pour la gestion des décisions d'entretien des installations 7-7
7-3 Coûts à long terme des installations 7-11

LISTE DES TABLEAUX

Tableau 1-1 Structures, systèmes, et composants concernés 1-2
Tableau 1-2 Facteurs de conversion 1-9
Tableau 2-1 Bilan des forces 2-2
Tableau 2-2 Finitions intérieures: Matériaux de mur 2-7
Tableau 2-3 Finitions intérieures revêtements mureaux 2-8
Tableau 2-4 Types de matériaux de plancher et leurs caractéristiques relatives 2-9
Tableau 2-5 Disponibilité des matériaux de couverture et des matériaux de couverture sandwich 2-14
Tableau 2-6 Peintures disponibles pour l'exposition extérieure typique des bâtiments 2-18
Tableau 2-7 Avantages et inconvénients des principaux matériaux de construction 2-25
Tableau 3-1 Résumé des modes de défaillance des principaux matériels structuraux 3-3
Tableau 3-2 Mécanismes de dégradation du béton armé 3-4
Tableau 3-3 Mécanismes de dégradation de l'acier de construction 3-6
Tableau 3-4 Mécanismes de dégradation des charpentes et poutres en bois 3-7
Tableau 3-5 Imperfections courantes du bois 3-8
Tableau 3-6 Réduction de la résistance des principaux bois 3-9
Tableau 3-7 Mécanismes et symptômes de dégradation courants pour différents matériaux de construction intérieurs 3-12
Tableau 3-8 Mécanismes de dégradation courants des matériaux de plancher 3-13
Tableau 3-9 Mécanismes de défaillance pour différents types de toits 3-14
Tableau 3-10 Mécanismes de défaillance typiques des pompes 3-19
Tableau 3-11 Mécanismes de défaillance des circuits de ventilation et d’extraction d’air 3-21
Tableau 3-12 Mécanismes de défaillance des systèmes de chauffage des bâtiments 3-22
Tableau 3-13 Mécanismes de défaillance des systèmes pneumatiques 3-24
Tableau 3-14 Mécanismes de défaillance de la climatisation 3-25
Tableau 3-15 Mécanismes de défaillance des composants dans les circuits électriques de distribution 3-27
Tableau 3-16 Mécanismes de défaillance des équipement d'éclairage et leurs causes 3-28
Tableau 3-17 Mécanismes de défaillance de l'asphalte et symptômes de détérioration 3-30
Tableau 4-1 Fréquences d'Inspection recommandées 4-2
Tableau 4-2 Enquête sur le béton existant 4-3
Tableau 4-3 Critères d'inspection pour l'acier de construction 4-8

Tableau 4-4 Critères d'inspection pour les parties de bâtiment en bois 4-10
Tableau 4-5 Insectes qui endommagent le bois 4-11
Tableau 4-6 Critères d'inspection des joints de dilatation et de construction 4-38
Tableau 4-7 Critères d'inspection des compresseurs d'échange 4-43
Tableau 4-8 Critères d'inspection des compresseurs à aubes coulissantes tournantes 4-44
Tableau 4-9 Critères d'inspection des compresseurs à lobes jumeaux tournants 4-45
Tableau 4-10 Critères d'inspection du des compresseurs à pistons liquides tournants 4-45
Tableau 4-11 Critères d'inspection des compresseurs dynamiques 4-46
Tableau 4-12 Critères d'inspection des échangeurs intermédiaires et avals 4-47
Tableau 4-13 Critères d'inspection des pièges 4-47
Tableau 4-14 Critères d'inspection des dessiccateurs d'air à absorption 4-48
Tableau 4-15 Critères d'inspection dessiccateurs d'air par refroidissement 4-48
Tableau 4-16 Critères d'inspection des réservoirs de stockage de d’air comprimé 4-48
Tableau 4-17 Critères d'inspection des petits moteurs à essence, diesel, ou au propane 4-49
Tableau 4-18 Critères d'inspection des circuits de distribution de vapeur 4-50
Tableau 4-19 Critères d'inspection des circuits de distribution d’eau à haute température 4-51
Tableau 4-20 Critères d'inspection de l’instrumentation 4-52
Tableau 4-21 Critères d'inspection du contrôle-commande 4-52
Tableau 4-22 Critères d'inspection de la climatisation 4-53
Tableau 4-23 Inspection du tableau des composants du circuit d'éclairage 4-58
Tableau 4-24 Critères d'inspection des moteurs en service 4-59
Tableau 4-25 Critères d'inspection des moteurs à l’arrêt 4-61
Tableau 4-26 Critères d'inspection des transformateurs hors tension 4-62
Tableau 4-27 Critères d'inspection des transformateurs sous tension 4-63
Tableau 5-1 Prévention de la détérioration d'acier de construction 5-6
Tableau 5-2 Entretien courant recommandé pour les vannes 5-25
Tableau 5-3 Entretien courant recommandé pour les pompes 5-26
Tableau 5-4 Entretien recommandé pour les composants du circuit de climatisation 5-34
Tableau 5-5 Procédures courantes d'entretien et de réparation des disjoncteurs 5-36
Tableau 5-6 Entretien courant des équipements d'éclairage 5-37
Tableau 5-7 Entretien courant et procédures de réparation pour les moteurs à courant alternatif ou continu 5-38
Tableau 5-8 Entretien courant et procédures de réparation des moteurs à courant continu 5-38
Tableau 5-9 Entretien courant et procédures de réparation pour les moteurs à courant alternatif 5-40
Tableau 6-1 Réparations d'entretien des surfaces revêtues d’asphalte 6-20

レポートの概要

目的

- 補助施設、管理施設及び所有地の保全に関する総合的な取り扱いについての情報を、原子力発電所及び米国エネルギー省の原子力施設の所員に提供すること。
- 様々な建物及び施設構成要素の故障メカニズムに関するガイド提供すること。
- 施設または所有地の評価用のベースライン状態を、確立する為の手段を提供すること
- 様々な点検技術及びされらの有効な使用に関する情報を提供すること
- 予防保全及び修理の為のガイドを提供すること

目次

1 はじめに 1-1
1.1 背景 1-1
1.2 目的 1-1
1.3 範囲 1-2
1.3.1 このレポートで記述されている施設及び施設構成要素の範囲 1-2
1.3.2 このレポートの範囲と構成 1-3
1.4 このレポート内での各種ガイダンスの統合 1-3
1.5 このレポート内での各種ガイダンスの有効的使用 1-4
1.6 頭字語 1-5
1.7 キーポイント 1-7
1.8 単位変換 1-9

2 設施設保全の概観 2-1
2.1 保全のタイプ 2-1
2.2 施設に作用する荷重のタイプ 2-2
2.3 建物要素の範囲とタイプ 2-3
2.3.1 主要な構造要素 2-3
2.3.1.1 補強コンクリート 2-3
2.3.1.2 鋼構造材 2-4
2.3.1.3 木/材木 2-4
2.3.2 施設用仕上げ材料 2-5
2.3.2.1 外面材料 2-5
2.3.2.2 内部の天井と壁材料 2-5
2.3.2.3 床 2-9
2.3.2.4 屋根 2-12
2.3.2.5 窓とドア 2-14

2.3.2.6 外面のためのコーティング 2-15
2.3.3 施設システム 2-19
2.3.3.1 水供給システム 2-20
2.3.3.2 暖房、換気、空調システム 2-20
2.3.3.3 電気システム 2-20
2.3.3.4 運搬装置 2-22
2.3.4 外部システム 2-22
2.3.4.1 歩道、車道、縁、アスファルト表面 2-22
2.3.4.2 雨水、排水、腐食抑制システム 2-23
2.3.4.3 塀 2-24
2.3.4.4 タンク 2-25
2.4 様々な建築材料の利点そして不利な点 2-25

3 故障メカニズムと劣化モード 3-1
3.1 はじめに 3-1
3.1.1 荷重のタイプ 3-1
3.1.2 応力と歪み 3-1
3.1.3 張力と圧縮力 3-2
3.1.4 応力の種類 3-2
3.2 主要な構造材料の故障メカニズム 3-3
3.2.1 補強コンクリート 3-3
3.2.2 鋼構造材 3-6
3.2.3 木/木材 3-7
3.3 施設の仕上げ材の破損メカニズム 3-10
3.3.1 外部材料 3-10
3.3.1.1 木製の外面材 3-10
3.3.1.2 金属の外面材 3-10
3.3.1.3 石材とコンクリートの外面材 3-10
3.3.1.4 鉱物を表面に置いた板外面 3-10
3.3.2 内部の天井と壁材料 3-10
3.3.3 床 3-12
3.3.4 屋根 3-13

3.3.5 窓とドア 3-15
3.3.6 外面のための塗装 3-16
3.3.6.1 外部の劣化 3-16
3.3.6.2 分離 3-17
3.3.6.3 完全な劣化 3-17
3.4 施設のシステムの故障メカニズム 3-18
3.4.1 水供給システム 3-18
3.4.1.1 上水、下水の配管システム 3-18
3.4.1.2 防火システム 3-20
3.4.2 暖房、換気、空調システム 3-20
3.4.2.1 施設及び建物の換気、排気システム 3-20
3.4.2.2 建物の暖房装置 3-22
3.4.2.3 空気システム 3-24
3.4.2.4 空調システム 3-25
3.4.3 電気システム 3-27
3.4.3.1 電気配分システム 3-27
3.4.3.2 照明装置 3-28
3.4.3.3 モーター 3-28
3.4.3.4 電池 3-29
3.4.3.5 変圧器 3-29
3.4.3.6 警報と拡声装置 3-29
3.4.4 運搬装置 3-29
3.4.4.1 油圧エレベーター 3-29
3.4.4.2 牽引式エレベーター 3-30
3.4.4.3 エスカレーター 3-30
3.5 外部システムの故障メカニズム 3-30
3.5.1 歩道、車道、縁、及びアスファルト表面 3-30
3.5.2 雨水、排水及び腐食抑制システム 3-31
3.5.2.1 風腐食 3-31
3.5.2.2 水腐食 3-31
3.5.2.3 排水と腐食抑制構造材の故障メカニズム 3-31
3.5.3 塀 3-31

3.5.4 タンク 3-32
3.6 故障に対する問題解決 3-32
3.7 設計寿命の推定 3-32

4 状態監視 4-1
4.1 はじめに 4-1
4.1.1 一般的な施設点検ガイダンス 4-1
4.1.2 推薦点検頻度 4-2
4.2 主要な構造材料の点検 4-3
4.2.1 補強されたコンクリート 4-3
4.2.1.1 一般的点検基準 4-3
4.2.1.2 スラブに対する点検基準 4-5
4.2.1.3 現場打ちコンクリートビームと柱に対する点検基準 4-6
4.2.1.4 事前打ち組立てコンクリートビームと柱に対する点検基準 4-6
4.2.2 鋼構造材 4-7
4.2.2.1 一般的点検基準 4-7
4.2.2.2 鋼ビームとコラムに対する点検基準 4-8
4.2.2.3 事前設計された鋼建物システムに対する点検基準 4-9
4.2.3 木/材木 4-10
4.2.3.1 一般的点検基準 4-10
4.2.3.2 腐敗 4-11
4.2.3.3 海洋のキクイムシ 4-11
4.2.3.4 昆虫 4-11
4.2.3.5 木製のビーム及び柱に対する点検基準 4-12
4.2.3.6 事前設計された木製の建物システムのための点検基準 4-13
4.2.3.7 耐火性柱に対する点検基準 4-13
4.3 設備仕上げ材に対する点検 4-14
4.3.1 外部材料 4-14
4.3.1.1 木製の外面材 4-14
4.3.1.2 金属の外面材 4-14
4.3.1.3 石材とコンクリート材の外面材 4-15
4.3.1.4 鉱物を表面に置いた板外面材 4-15

4.3.2 内部の天井と壁材料 4-16
4.3.2.1 一般的点検基準 4-16
4.3.2.2 通常用いられる仕切りに対する点検基準 4-16
4.3.2.3 特別の仕切りに対する点検基準 4-17
4.3.2.4 洗面所のための仕切りに対する点検基準 4-17
4.3.2.5 壁カバーに対する点検基準 4-17
4.3.2.6 天井システムに対する点検基準 4-18
4.3.3 床と階段 4-18
4.3.3.1 現場打ちコンクリート床に対する点検基準 4-19
4.3.3.2 事前打ちコンクリート床に対する点検基準 4-19
4.3.3.3 鋼鉄製の床に対する点検基準 4-20
4.3.3.4 複合材で出来た床に対する点検基準 4-20
4.3.3.5 木製の床に対する点検基準 4-21
4.3.3.6 床仕上げ材に対する点検基準 4-22
4.3.4 屋根 4-22
4.3.4.1 一般的点検基準 4-22
4.3.4.2 コンクリート製屋根構造に対する点検基準 4-23
4.3.4.3 鋼鉄製屋根構造に対する点検基準 4-23
4.3.4.4 木製屋根構造に対する点検基準 4-24
4.3.4.5 積層膜構造の屋根に対する点検基準 4-25
4.3.4.6 一層膜構造の屋根に対する点検基準..... 4-25
4.3.4.7 金属屋根に対する点検基準 4-26
4.3.4.8 上塗塗装のある発泡プラスチック膜の屋根に対する検基準..... 4-26
4.3.4.9 鉄板葺き屋根に対する点検基準 4-27
4.3.4.10 タイル製の屋根に対する点検基準..... 4-27
4.3.4.11 手すりに対する点検基準..... 4-28
4.3.4.12 屋根の排水システムに対する点検基準..... 4-28
4.3.4.13 屋根に付く特性品に対する点検基準..... 4-29
4.3.4.14 屋根の天窓に対する点検基準..... 4-29
4.3.5 窓とドア 4-30
4.3.5.1 窓のための点検規準 4-30
4.3.5.2 内部のドアのための点検規準 4-31

4.3.6 外面のためのコーティング 4-31
4.4 設備システムの点検 4-32
4.4.1 水供給システム 4-32
4.4.1.1 上水、下水配管システム 4-32
4.4.1.2 防火システム 4-34
4.4.1.3 トイレ及び付属品 4-35
4.4.1.4 下水の排出装置 4-35
4.4.1.5 貯蔵タンク 4-36
4.4.1.6 タンクとサンプ 4-36
4.4.1.7 水処理装置 4-37
4.4.2 暖房、換気、空調暖房システム 4-37
4.4.2.1 ダクト及び空気移送システム 4-37
4.4.2.2 暖房装置 4-39
4.4.2.3 水ヒーター 4-42
4.4.2.4 空気システム 4-43
4.4.2.5 蒸気の供給システム 4-50
4.4.2.6 高温水供給システム 4-51
4.4.2.7 計装と制御 4-52
4.4.2.8 空調システム 4-53
4.4.3 電気システム 4-55
4.4.3.1 配電装置 4-55
4.4.3.2 照明装置 4-57
4.4.3.3 モーター 4-59
4.4.3.4 電池 4-61
4.4.3.5 変圧器 4-62
4.4.3.6 警報と拡声装置 4-64
4.4.4 運搬装置 4-65
4.4.4.1 油圧式エレベーター 4-65
4.4.4.2 牽引式エレベーター 4-65
4.4.4.3 エスカレーター 4-66
4.5 外部システムの点検 4-66
4.5.1 歩道、車道、縁、アスファルト表面 4-66

4.5.2 雨水、排水及び腐食抑制システム 4-66
4.5.3 塀 4-66
4.5.4 タンク 4-67

5 予防保全と予測保全 5-1
5.1 主要な構造材料のための定期的保全 5-1
5.1.1 補強されたコンクリート 5-1
5.1.1.1 劣化の防止 5-1
5.1.1.2 定期的保全 5-2
5.1.1.3 コーティング 5-3
5.1.1.4 汚れ除去 5-4
5.1.2 鋼構造材 5-5
5.1.2.1 劣化の防止 5-5
5.1.2.2 定期的保全 5-7
5.1.3 木/木材 5-8
5.1.3.1 木/木材 の要素の腐敗の抑制 5-8
5.1.3.2 シロアリによる損傷を防ぐこと 5-8
5.1.3.3 シロアリに対する措置 5-9
5.1.3.4 乾燥を原因とした表面開口に対する予防手段 5-9
5.1.3.5 木に対する処置 5-10
5.2 施設仕上げ材料に対する保全 5-11
5.2.1 外部材料 5-11
5.2.1.1 木製の外面材 5-11
5.2.1.2 金属の外面材 5-11
5.2.1.3 石材とコンクリートの外面材 5-12
5.2.1.4 鉱物を表面に置いた板外面材 5-12
5.2.2 内部の天井と壁材料 5-14
5.2.2.1 しっくい 5-14
5.2.2.2 ドライ壁 5-14
5.2.2.3 セラミックタイル 5-14
5.2.2.4 防音タイル 5-14
5.2.2.5 木 5-15

5.2.3 床 5-15
5.2.3.1 一般的なガイダンス 5-15
5.2.3.2 定期的な床の保全の種類 5-16
5.2.3.3 詳細な床の保全手順 5-16
5.2.4 屋根 5-19
5.2.4.1 積層式屋根 5-19
5.2.4.2 アスファルト板の屋根 5-19
5.2.4.3 アスファルト表面の屋根 5-19
5.2.4.4 アスファルトセメントの屋根 5-20
5.2.4.5 金属の屋根 5-20
5.2.4.6 スレートの屋根 5-21
5.2.4.7 木板の屋根 5-21
5.2.4.8 単層の膜状の屋根 5-21
5.2.5 窓とドア 5-22
5.2.5.1 窓 5-22
5.2.5.2 ドア 5-22
5.2.6 外面コーティング 5-23
5.3 施設の定期的保全 5-24
5.3.1 水供給システム 5-24
5.3.1.1 上水、下水の配管システム 5-24
5.3.1.2 防火システム 5-26
5.3.2 暖房、換気、空調システム 5-26
5.3.2.1 ダクトと空気移送システム 5-27
5.3.2.2 暖房装置 5-27
5.3.2.3 水ヒーター 5-29
5.3.2.4 空気システム 5-30
5.3.2.5 蒸気供給システム 5-32
5.3.2.6 高温水供給システム 5-32
5.3.2.7 計装と制御 5-32
5.3.2.8 空調システム 5-33
5.3.3 電気システム 5-35
5.3.3.1 配電装置 5-35

5.3.3.2 照明装置 5-36
5.3.3.3 モーター 5-38
5.3.3.4 電池 5-40
5.3.3.5 変圧器 5-41
5.3.3.6 警報と拡声装置 5-41
5.3.4 運搬装置 5-41
5.4 外部システムの定期点検 5-42
5.4.1 歩道、車道、縁、アスファルト表面 5-42
5.4.2 雨水、排水及び腐食抑制システム 5-42
5.4.2.1 排水と腐食を抑制する系統 5-42
5.4.2.2 排水と腐食を抑制する構造 5-42
5.4.3 塀 5-45
5.4.4 タンク 5-45

6 事後保全及び修理 6-1
6.1 主要な構造材料の修理 6-1
6.1.1 補強されたコンクリートの修理 6-1
6.1.1.1 修理前考察 6-1
6.1.1.2 コンクリートの割れに対する修理 6-2
6.1.1.3 水浸透の修理 6-4
6.1.1.4 熱硬化性プラスチック(エポキシ) 6-4
6.1.1.5 修理の実施 6-5
6.1.2 鋼構造材の修理 6-5
6.1.2.1 鋼構造材の要素 6-5
6.1.2.2 接続部 6-6
6.1.2.3 構造要素に対する特殊な修理 6-7
6.1.3 木/木材の構造部材の修理 6-8
6.1.3.1 一般的な修理ガイダンス 6-8
6.1.3.2 層状に接着された部材 6-9
6.2 設備終わり材料の修理 6-9
6.2.1 外部材料 6-9
6.2.1.1 木製の外面材 6-9

6.2.1.2 金属の外面材 6-9
6.2.1.3 石材とコンクリートの外面材 6-11
6.2.1.4 鉱物を表面に置いた板外面 6-11
6.2.2 内部の天井と壁材料 6-12
6.2.2.1 しっくい 6-12
6.2.2.2 ドライ壁 6-12
6.2.2.3 セラミックタイル 6-12
6.2.2.4 防音タイル 6-12
6.2.2.5 木 6-12
6.2.3 床 6-13
6.2.3.1 弾力性のある床 6-13
6.2.3.2 石材の床 6-13
6.2.3.3 金属製の床 6-13
6.2.3.4 継ぎ目の無い床 6-13
6.2.3.5 木製の床 6-13
6.2.3.6 カーペット 6-14
6.2.4 屋根 6-14
6.2.4.1 積層式屋根 6-14
6.2.4.2 アスファルト板の屋根 6-16
6.2.4.3 アスファルト表面の屋根 6-16
6.2.4.4 アスファルトセメントの屋根 6-16
6.2.4.5 金属の屋根 6-16
6.2.4.6 スレートの屋根 6-17
6.2.4.7 木板の屋根 6-17
6.2.4.8 単一の膜の屋根 6-17
6.2.5 窓とドア 6-17
6.2.6 外面材のコーティング 6-18
6.3 施設システムの修理 6-18
6.3.1 水供給装置 6-18
6.3.1.1 上水、下水の配管システム 6-18
6.3.1.2 防火システム 6-18
6.3.2 暖房、換気、空調システム 6-18

6.3.3 電気システム 6-19
6.3.4 運搬システム 6-19
6.4 外部システムの修理 6-19
6.4.1 歩道、車道、縁、アスファルト表面 6-19
6.4.2 雨水、排水、腐食抑制システム 6-21
6.4.3 塀 6-21
6.4.3.1 パッチ当て 6-21
6.4.3.2 金網塀の取り替え 6-22
6.4.4 タンク 6-22

7 施設の保全管理 7-1
7.1 修理、取り替え、保全時期延期に関する解析 7-1
7.1.1 総合的解析において考慮すべき要素 7-1
7.1.1.1 経済的費用検討のため定量化可能な要素 7-2
7.1.1.2 意思決定における主要な定性的要素 7-4
7.1.1.3 その他考慮すべき定性的要素 7-4
7.2 意思決定過程 7-6
7.2.1 劣化を修理する決定 7-7
7.2.2 劣化の修理 7-8
7.2.2.1 修復手順の選択 7-8
7.2.2.2 修理に関する追加的考察 7-9
7.2.3 修理の延期 7-9
7.2.4 点検企業や外部修理会社の使用 7-9
7.2.5 決定の有効性に対する評価 7-10
7.3 代替解析法 7-10
7.4 施設保全管理上の他の事項 7-11
7.4.1 施設の長期的費用 7-11
7.4.2 設計情報とコンフィギュレーション・マネジメントの活用 7-11

8 参照 8-1
8.1 テキスト中の参照 8-1
8.2 文献目録 8-1
8.3 関連するEPRIガイドライン 8-2

8.4 企業と貿易組織 8-6

プログラムに係る主要な要素 A-1

A.1 設備の識別と種類 A-1

A.1.1 機能タイプによる類別 A-1

A.1.2 不動産とプロセス装置との区別 A-1

A.2 保全活動に関するタイプと優先順位 A-2

A.2.1 はじめに A-2

A.2.2 対応的保全 A-2

A.2.3 予防保全 A-2

A.2.4 予測保全 A-3

A.2.5 信頼性中心保全 A-4

A.2.6 延期保全 A-4

***B* 予測設計寿命 B-1**

B.1 基礎 B-1

B.2 基礎構造 B-2

B.2.1 スラブ B-2

B.2.2 コラム B-2

B.3 Superstructures B-2

B.3.1 床の平板とデッキ B-2

B.3.2 階段 B-3

B.3.3 構造フレーム B-3

B.3.4 内部の構造壁 B-3

B.3.5 床の平板とデッキ B-3

B.4 外部の囲い B-4

B.5 屋根 B-5

B.6 内部の仕上げ材と構造 B-6

B.6.1 壁 B-6

B.6.2 柵と手すり B-7

B.6.3 壁、床、及び天井 B-7

B.7 運搬システム B-8

B.8 機械システム B-8

B.8.1 配管 B-8
B.8.2 防火装置 B-9
B.8.3 暖房、換気、空調装置 B-10
B.9 機械システム B-12
B.9.1 サービスと配電 B-12
B.9.1.1 低電圧 B-12
B.9.1.2 中電圧 B-13
B.9.2 照明 B-13
B.9.3 特定のシステム B-13
B.10 特別なシステム B-13
B.11 現場作業 B-14
B.11.1 道路と通路の舗装 B-14
B.11.2 トンネル B-14
B.11.3 保安塀とゲート B-14
B.11.4 橋と迫台 B-14

C 規格基準 C-1
C.1 目的 C-1
C.2 連邦政府の仕様 C-2
C.3 国の標準 C-8
C.3.1 空気調節冷凍研究所 C-8
C.3.2 空気移送制御協会 C-8
C.3.3 アメリカ建築製造業者協会 C-9
C.3.4 アメリカ織物色彩科学者協会 C-9
C.3.5 アメリカコンクリート協会 C-9
C.3.6 アメリカハードボード協会 C-10
C.3.7 アメリカ鋼鉄建築協会 C-10
C.3.8 アメリカ材木建築協会 C-10
C.3.9 アメリカ鉄鋼協会 C-10
C.3.10 米国規格協会 C-10
C.3.11 アメリカ合板協会 C-11
C.3.12 アメリカ材料試験学会 C-11

C.3.13 アメリカ暖房、冷房、空調学会 C-18
C.3.14 アメリカ機会学会 C-19
C.3.15 アメリカ溶接学会 C-19
C.3.16 アメリカ森林保護協会 C-19
C.3.17 アメリカ煉瓦協会 C-20
C.3.18 建築事務所及び規格管理人国際組織 C-20
C.3.19 鉄筋コンクリート協会 C-20
C.3.20 ドアとハードウェア協会 C-20
C.3.21 外部断熱材の製造業者協会 C-20
C.3.22 板ガラスのマーケティング協会 C-20
C.3.23 石膏協会 C-21
C.3.24 電気と電子協会（IEEE） C-21
C.3.25 建築金属の製造業者の全国連合 C-21
C.3.26 ガレージドア製造業者の全国連合 C-21
C.3.27 配管/暖房/冷房建築業者の全国連合 C-21
C.3.28 全国防火連合 C-21
C.3.29 国有林プロダクト連合 C-23
C.3.30 全国堅材製材連合 C-23
C.3.31 全国カシ材フロアーリングの製造業者連合 C-23
C.3.32 全国テラゾとモザイク連合株式会社。 C-23
C.3.33 全国木製の窓及びドア連合 C-23
C.3.34 配管と排水協会 C-23
C.3.35 ポートランドセメント連合 C-23
C.3.36 事前打ち/プレストレスコンクリート協会 C-23
C.3.37 薄板金と空調建築業者連合 C-24
C.3.38 保護コーティング学会 C-24
C.3.39 鋼鉄ドアの協会 C-24
C.3.40 トラス版の協会 C-24
C.3.41 保証人研究所 C-24
C.3.42 均一建物コード C-25
C.4 企業の図書 C-25

D 主要な情報リスト D-1

D.1 主要な運転保守、費用上のポイント D-1

D.2 主要な技術的ポイント D-1

D.3 主要なヒューマンパフォーマンス上のポイント D-2

図のリスト

図1-1 保全ガイダンスの統合..... 1-4
図2-1 ペンキ材料/コーティングに関する特徴と製品情報..... 2-17
図4-1 コーティング状態の評価のための目視検差の利点..... 4-32
図7-1 意思決定過程において考慮されるべき要素..... 7-2
図7-2 設備保全決定に関する管理プロセス..... 7-7
図7-3 設備の長期費用..... 7-11

表のリスト

表1-1 造、システム、部品の範囲..... 1-2
表1-2 換算率..... 1-9
表2-1 力の種類..... 2-2
表2-2 内部仕上げ材：壁材料..... 2-7
表2-3 内部仕上げ材：壁カバー..... 2-8
表2-4 ロアーリング材料のタイプと相対的な特徴..... 2-9
表2-5 入手可能な屋根材と屋根サンドイッチ部品..... 2-14
表2-6 典型的な建物外面の入手可能なペンキ..... 2-18
表2-7 主要な建築材料の利点と欠点..... 2-25
表3-1 主要な構造材料の故障メカニズムの概要..... 3-3
表3-2 補強コンクリートの故障メカニズム..... 3-4
表3-3 構造スチールの故障メカニズム..... 3-6
表3-4 木/木材要素の故障メカニズム..... 3-7
表3-5 木/木材要素の共通的欠陥..... 3-8
表3-6 主要な木の腐食の抵抗 3-9
表3-7 様々な内部建築材料のための共通の故障メカニズムと徴候..... 3-12
表3-8 フロアーリング材料のための共通の故障メカニズム..... 3-13
表3-9 様々なタイプの屋根のための故障メカニズム..... 3-14
表3-10 典型的なポンプの故障メカニズム..... 3-19
表3-11 換気、排気システムの故障メカニズム..... 3-21
表3-12 建物の暖房装置の故障メカニズム..... 3-22
表3-13 空気システムの故障メカニズム..... 3-24
表3-14 空調システムの故障メカニズム..... 3-25
表3-15 配分システム部品の故障メカニズム..... 3-27
表3-16 照明器具の故障メカニズムと原因..... 3-28
表3-17 アスファルト故障メカニズムと劣化徴候..... 3-30
表4-1 推奨点検頻度..... 4-2
表4-2 既存のコンクリートに対する調査..... 4-3
表4-3 構造スチールのための点検基準..... 4-8

表4-4 木/木材の建物部品に対する点検基準..... 4-10
表4-5 木製品に損害を与える昆虫..... 4-11
表4-6 伸縮継手及び建築継手に対する点検基準..... 4-38
表4-7 往復圧縮機に対する点検基準..... 4-43
表4-8 ロータリー式スライディングベーン圧縮機に対する点検基準..... 4-44
表4-9 ロータリー式双ロープ圧縮機に対する点検基準..... 4-45
表4-10 ロータリー液体ピストン圧縮機に対する点検基準..... 4-45
表4-11 動的圧縮機に対する点検基準..... 4-46
表4-12 インタークーラーとアフタークーラーに対する点検基準..... 4-47
表4-13 トラップに対する点検基準..... 4-47
表4-14 吸収式の空気乾燥機に対する点検基準..... 4-48
表4-15 冷凍タイプの空気乾燥機に対する点検基準..... 4-48
表4-16 圧縮空気貯蔵タンクに対する点検基準..... 4-48
表4-17 小型ガソリン、ディーゼル、プロパンエンジンに対する点検基準..... 4-49
表4-18 蒸気供給システムに対する点検基準..... 4-50
表4-19 高温水供給システムに対する点検基準..... 4-51
表4-20 計装に対する点検基準..... 4-52
表4-21 制御系に対する点検基準..... 4-52
表4-22 空調システムに対する点検基準..... 4-53
表4-23 照明装置部品に対する点検基準..... 4-58
表4-24 運転中のモーターに対する点検基準..... 4-59
表4-25 運転停止後のモーターに対する点検基準..... 4-61
表4-26 非励磁状態の変圧器に対する点検基準..... 4-62
表4-27 励磁状態の変圧器に対する点検基準..... 4-63
表5-1 構造スチールの劣化防止..... 5-6
表5-2 弁に対する推奨定期保全..... 5-25
表5-3 ポンプに対する推奨定期保全..... 5-26
表5-4 空調システム部品に対する推奨保全..... 5-34
表5-5 遮断器に対する共通保全及び修理手順..... 5-36
表5-6 照明器具の定期的保全..... 5-37
表5-7 交流/直流モータに対する定期的保全及び修理手順..... 5-38
表5-8 直流モータに対する定期的保全及び修理手順..... 5-38
表5-9 交流モーターに対する定期的保全及び修理手順..... 5-40
表6-1 アスファルト表面に対する保全修理..... 6-20

DIVULGAR EL RESUMEN

Objetivos

- Proveer un guía comprensivo de apoyo, facilidades administrativas, y mantenimiento de la propriedad al personal en las plantas nucleares y en las instalaciones del Departamento de Energía de los Estados Unidos.
- Proveer orientación con respecto a los mecanismos de falla para los varios elementos de construcción y componentes de la planta
- Proveer los medios para establecer la condición de base para evaluación de la planta o de la propriedad
- Proveer diferentes técnicas de inspección e información sobre su uso eficaz
- Proveer orientación para realizar mantenimiento preventivo y reparaciones

CONTENIDO

1 **INTRODUCCIÓN 1-1**

1.1 Antecedentes 1-1

1.2 Propósito 1-1

1.3 Alcance 1-2

1.3.1 Ambito de las Instalaciones y de sus Componentes descritos en este Informe 1-2

1.3.2 Ambito y Organización de este Informe 1-3

1.4 Integración de Orientación en este Informe 1-3

1.5 Uso Eficaz de la Orientación en este informe 1-4

1.6 Siglas 1-5

1.7 Puntos Importantes 1-7

1.8 Conversiones de Unidad 1-9

2 **ESCRIPCIÓN DEL MANTENIMIENTO DE LAS PLANTAS 2-1**

2.1 Tipos de mantenimiento 2-1

2.2 Tipos de Fuerzas que Actúan en las Instalaciones 2-2

2.3 Ambito y Tipos de Elementos de Construcción 2-3

2.3.1 Principales Elementos Estructurales 2-3

2.3.1.1 Concreto Reforzado 2-3

2.3.1.2 Acero Estructural 2-4

2.3.1.3 Madera/Leña 2-4

2.3.2 Materiales Finales en la Planta 2-5

2.3.2.1 Materiales Exteriores 2-5

2.3.2.2 Materiales Interiores del Techo y de la Pared 2-5

2.3.2.3 Pisos 2-9

2.3.2.4 Tejado 2-12

2.3.2.5 Ventanas y puertas 2-14

2.3.2.6 Revestimiento para superficies externas 2-15

2.3.3 Sistemas de la Planta 2-19
2.3.3.1 Sistemas de Distribución del Agua 2-20
2.3.3.2 Sistemas de calefacción, ventilación y de aire acondicionado 2-20
2.3.3.3 Sistemas Eléctricos 2-20
2.3.3.4 Transporte de Sistemas 2-22
2.3.4 Sistemas Externos 2-22
2.3.4.1 Superficies de asfalto de caminos, calzadas 2-22
2.3.4.2 Sistemas de salida, drenaje y control de la erosión 2-23
2.3.4.3 Cercas 2-24
2.3.4.4 Tanques 2-25
2.4 Ventajas y desventajas de los varios materiales de construcción 2-25

3 MECANISMOS DE FALLA Y MODOS DEL ENVEJECIMIENTO 3-1
3.1 Introducción 3-1
3.1.1 Tipos de cargas 3-1
3.1.2 Tensión y presión 3-1
3.1.3 Tensión y compresión 3-2
3.1.4 Tipos de tensión 3-2
3.2 Mecanismos de falla de los principales materiales estructurales 3-3
3.2.1 Concreto Reforzado 3-3
3.2.2 Acero Estructural 3-6
3.2.3 Wood/Leña 3-7
3.3 Mecanismos de falla de materiales de acabamiento de la planta 3-10
3.3.1 Materiales Exteriores 3-10
3.3.1.1 Exteriores de madera 3-10
3.3.1.2 Exteriores de Metal 3-10
3.3.1.3 Exteriores de Albañilería y de concreto 3-10
3.3.1.4 Exteriores de tablones cubiertos de mineral 3-10
3.3.2 Materiales de interiores de techo y pared 3-10
3.3.3 Pisos 3-12
3.3.4 Tejados 3-13
3.3.5 Ventanas y puertas 3-15
3.3.6 Revestimiento para superficies exteriores 3-16
3.3.6.1 Deterioración Exterior 3-16
3.3.6.2 Desintegración 3-17

3.3.6.3 Desintegración Total 3-17
3.4 Mecanismos de falla de los sistemas de la planta 3-18
3.4.1 Sistemas de Distribución de Agua 3-18
3.4.1.1 Sistemas de plomería de agua natural y de desecho 3-18
3.4.1.2 Sistemas de Protección contra Incendios 3-20
3.4.2 Sistemas de calefacción, ventilación y de aire acondicionado 3-20
3.4.2.1 Sistemas de ventilación de la instalación, del exhaustor y de aire acondicionado 3-20
3.4.2.2 Sistemas de Calefacción de la instalación 3-22
3.4.2.3 Sistemas Neumáticos 3-24
3.4.2.4 Sistemas de aire acondicionado 3-25
3.4.3 Sistemas Eléctricos 3-27
3.4.3.1 Sistemas Eléctricos de Distribución 3-27
3.4.3.2 Sistemas de Iluminación 3-28
3.4.3.3 Motores 3-28
3.4.3.4 Baterías 3-29
3.4.3.5 Transformadores 3-29
3.4.3.6 Sistemas de alarma y de dirección pública 3-29
3.4.4 Transporte de Sistemas 3-29
3.4.4.1 Ascensores Hidráulicos 3-29
3.4.4.2 Ascensores de la tracción 3-30
3.4.4.3 Escaleras mecánicas 3-30
3.5 Mecanismos de falla de sistemas externos 3-30
3.5.1 Superfície de asfalto en caminos, calzadas 3-30
3.5.2 Salida, drenaje, y sistemas de control de la erosión 3-31
3.5.2.1 Erosión del Viento 3-31
3.5.2.2 Erosión del Agua 3-31
3.5.2.3 Mecanismos de falla de las estructuras de control de drenaje y erosión 3-31
3.5.3 Cercas 3-31
3.5.4 Tanques 3-32
3.6 Fallas de funcionamiento 3-32
3.7 Estimativa de Vida del Diseño 3-32

4 MONITOREO BASADO EN LAS CONDICIONES 4-1
4.1 Introducción 4-1
4.1.1 Orientaciones Generales de Inspección de la Planta 4-1

4.1.2 Frecuencias de Inspección Recomendadas 4-2
4.2 Inspección de los principales materiales estructurales 4-3
4.2.1 Concreto Reforzado 4-3
4.2.1.1 Criterios Generales de Inspección 4-3
4.2.1.2 Criterios de inspección de losas por grado 4-5
4.2.1.3 Criterios de inspección de vigas y columnas de concreto puestos en su lugar 4-6
4.2.1.4 Criterios de inspección de vigas cargadas y columnas de concreto pre-fabricadas 4-6
4.2.2 Acero Estructural 4-7
4.2.2.1 Criterios Generales de Inspección 4-7
4.2.2.2 Criterios de inspección para vigas y columnas de acero 4-8
4.2.2.3 Criterios de inspección para sistemas de construcción pre-fabricada en metal 4-9
4.2.3 Madera/Leña 4-10
4.2.3.1 Criterios Generales de Inspección 4-10
4.2.3.2 Decaimiento 4-11
4.2.3.3 Perforadoras Marinas 4-11
4.2.3.4 Insectos 4-11
4.2.3.5 Criterios de inspección para vigas y columnas de madera 4-12
4.2.3.6 Criterios de inspección para sistemas de construcción pre-fabricadas en madera 4-13
4.2.3.7 Criterios de inspección para columnas a prueba de fuego 4-13
4.3 Inspección de materiales de acabamiento en la planta 4-14
4.3.1 Materiales de Exteriores 4-14
4.3.1.1 Externos en Madera 4-14
4.3.1.2 Exteriores en Metal 4-14
4.3.1.3 Albañilería y concreto en exteriores 4-15
4.3.1.4 Exteriores de tablones cubiertos de mineral 4-15
4.3.2 Materiales para interiores de techo y pared 4-16
4.3.2.1 Criterios Generales de Inspección 4-16
4.3.2.2 Criterios de inspección para divisiones convencionales 4-16
4.3.2.3 Criterios de inspección para divisiones por especialidades 4-17
4.3.2.4 Criterios de inspección para divisiones del tocador 4-17
4.3.2.5 Criterios de inspección para sistemas de cubierto de pared 4-17
4.3.2.6 Criterios de inspección para sistemas del techo 4-18

4.3.3 Pisos y escaleras 4-18
4.3.3.1 Criterios de inspección para colocación de pisos de concreto 4-19
4.3.3.2 Criterios de inspección para pre-colocación de pisos de concreto 4-19
4.3.3.3 Criterios de inspección para pisos de acero 4-20
4.3.3.4 Criterios de inspección para pisos compuestos 4-20
4.3.3.5 Criterios de inspección para pisos de madera 4-21
4.3.3.6 Criterios de inspección para sistemas revestimiento de pisos 4-22
4.3.4 Tejados 4-22
4.3.4.1 Criterios de Inspección Generales 4-22
4.3.4.2 Criterios de inspección para estructuras de tejados de concreto 4-23
4.3.4.3 Criterios de inspección para estructuras de tejados de acero 4-23
4.3.4.4 Criterios de inspección para estructuras de tejados de madera 4-24
4.3.4.5 Criterios de inspección para tejados de membrana pre-fabricada 4-25
4.3.4.6 Criterios de inspección para tejados de membranas de chapa única 4-25
4.3.4.7 Criterios de inspección para tejados de metal 4-26
4.3.4.8 Criterios de inspección para tejados de membrana de espuma 4-26
4.3.4.9 Criterios de inspección para tejados de guizarros 4-27
4.3.4.10 Criterios de inspección para tejados de cerámica 4-27
4.3.4.11 Criterios de inspección para parapetos 4-28
4.3.4.12 Criterios de inspección de drenaje en tejados 4-28
4.3.4.13 Criterios de inspección para tejados especiales 4-29
4.3.4.14 Criterios de inspección para tejados con claraboyas 4-29
4.3.5 Ventanas y puertas 4-30
4.3.5.1 Criterios de inspección para ventanas 4-30
4.3.5.2 Criterios de inspección para puertas internas 4-31
4.3.6 Revestimiento para superficies externas 4-31
4.4 Inspección de sistemas de las plantas 4-32
4.4.1 Sistemas de Distribución de Agua 4-32
4.4.1.1 Sistemas de plomería de agua natural y de desecho 4-32
4.4.1.2 Sistemas de Protección de Incendio 4-34
4.4.1.3 Baños, lavatorios y accesorios 4-35
4.4.1.4 Eyectores de residuos 4-35
4.4.1.5 Tanques de almacenaje 4-36
4.4.1.6 Tanques y colectores de sumideros 4-36
4.4.1.7 Condicionadores de Agua 4-37

4.4.2 Calefación, ventilación y sistema de aire acondicionado 4-37
4.4.2.1 Sistemas de ductos y transporte aéreo 4-37
4.4.2.2 Sistemas de Calefacción 4-39
4.4.2.3 Aquecedores de Agua 4-42
4.4.2.4 Sistemas Neumáticos 4-43
4.4.2.5 Sistemas de Distribución de Vapor 4-50
4.4.2.6 Sistemas de Distribución de Agua de alta temperatura.....4-51
4.4.2.7 Instrumentos y controles 4-52
4.4.2.8 Sistemas de Aire acondicionado 4-53
4.4.3 Sistemas Eléctricos 4-55
4.4.3.1 Sistemas de Distribución Eléctrica 4-55
4.4.3.2 Sistemas de Iluminación 4-57
4.4.3.3 Motores 4-59
4.4.3.4 Baterías 4-61
4.4.3.5 Transformadores 4-62
4.4.3.6 Alarmas y dirección pública 4-64
4.4.4 Sistemas de Transporte 4-65
4.4.4.1 Ascensores Hidráulicos 4-65
4.4.4.2 Ascensores de Tracción 4-65
4.4.4.3 Escaleras mecánicas 4-66
4.5 Inspección de sistemas externos 4-66
4.5.1 Superficie de asfalto de caminos, calzadas 4-66
4.5.2 Salida, drenaje, y sistemas de control de la erosión 4-66
4.5.3 Cercas 4-66
4.5.4 Tanques 4-67

_5_ MANTENIMIENTO PREVENTIVO Y PREDITIVO 5-1
5.1 Mantenimiento de Rotina para los principales materiales de estructura 5-1
5.1.1 Concreto Reforzado 5-1
5.1.1.1 Prevención de la deterioración 5-1
5.1.1.2 Mantenimiento General 5-2
5.1.1.3 Revestimiento.....5-3
5.1.1.4 Remoción de Manchas 5-4
5.1.2 Acero de Estructura 5-5
5.1.2.1 Prevención de la deterioración 5-5

5.1.2.2 Mantenimiento de rotina 5-7
5.1.3 Madera/Leña 5-8
5.1.3.1 Detención de deterioración de los elementos de madera/leña.....5-8
5.1.3.2 Prevención de daño de Termitas 5-8
5.1.3.3 Tratamiento para termitas 5-9
5.1.3.4 Medidas Preventivas contra verificaciones 5-9
5.1.3.5 Tratamiento para madera 5-10
5.2 Mantenimiento de materiales 5-11
5.2.1 Materiales para áreas externas 5-11
5.2.1.1 Madeiras externas 5-11
5.2.1.2 Metal externo 5-11
5.2.1.3 Albañilería y exteriores concretos 5-12
5.2.1.4 Exteriores de Tablero de revestimiento mineral 5-12
5.2.2 Materiales interiores de techo y pared 5-14
5.2.2.1 Yeso 5-14
5.2.2.2 Muro 5-14
5.2.2.3 Losa Cerámica 5-14
5.2.2.4 Azulejo Acústico 5-14
5.2.2.5 Madera 5-15
5.2.3 Pisos 5-15
5.2.3.1 Orientación General 5-15
5.2.3.2 Tipos de mantenimiento de rutina para pisos 5-16
5.2.3.3 Procedimientos detallados de Mantenimiento de Pisos 5-16
5.2.4 Tejado 5-19
5.2.4.1 Tejados pre-fabricados 5-19
5.2.4.2 Tejados de tablas asfaltadas de ripia 5-19
5.2.4.3 Tejados de asfalto enrollado 5-19
5.2.4.4 Tejados de cemento de asfalto 5-20
5.2.4.5 Tejados de Metal 5-20
5.2.4.6 Tejados de Pizarra 5-21
5.2.4.7 Tejados de Ripas de Madera.....5-21
5.2.4.8 Tejados de Membrana Única 5-21
5.2.5 Ventanas y Puertas 5-22
5.2.5.1 Ventanas 5-22
5.2.5.2 Puertas 5-22

5.2.6 Revestimiento para superficies exteriores 5-23
5.3 Mantenimiento de ruina para los sistemas de la planta 5-24
5.3.1 Sistemas de Distribución de Agua 5-24
5.3.1.1 Sistemas de plomería de agua natural y de desecho 5-24
5.3.1.2 Sistemas de Protección contra Incendios 5-26
5.3.2 Calefacción, ventilación y sistema de aire acondicionado 5-26
5.3.2.1 Conducto y sistemas del transporte aéreo 5-27
5.3.2.2 Sistemas de Calefacción 5-27
5.3.2.3 Calentadores de Agua 5-29
5.3.2.4 Sistemas Neumáticos 5-30
5.3.2.5 Sistemas de Distribución de Vapor 5-32
5.3.2.6 Sistemas de distribución de alta temperatura.....5-32
5.3.2.7 Instrumentos y controles 5-32
5.3.2.8 Sistemas de Aire acondicionado 5-33
5.3.3 Sistemas Eléctricos 5-35
5.3.3.1 Sistemas Eléctricos de la Distribución 5-35
5.3.3.2 Sistemas de Iluminación 5-36
5.3.3.3 Motores 5-38
5.3.3.4 Baterías 5-40
5.3.3.5 Transformadores 5-41
5.3.3.6 Alarmas y dirección pública 5-41
5.3.4 Transportación de Sistemas 5-41
5.4 Mantenimiento de rutina de sistemas externos 5-42
5.4.1 Superficie de asfalto de caminos, calzadas 5-42
5.4.2 Salida, drenaje, y sistemas de control de la erosión 5-42
5.4.2.1 Sistemas de control de drenaje y de erosión 5-42
5.4.2.2 Estructuras del control de drenaje y de erosión 5-42
5.4.3 Cercas 5-45
5.4.4 Tanques 5-45

***6* MANTENIMIENTO CORRECTIVO Y REPARACIONES 6-1**
6.1 Reparación de los Principales Materiales Estructurales 6-1
6.1.1 Reparación del Concreto Reforzado 6-1
6.1.1.1 Consideraciones de Pre-Reparación 6-1
6.1.1.2 Reparación de grietas en concreto 6-2

6.1.1.3 Reparación de infiltración de agua 6-4
6.1.1.4 Plástico Termoendurecible (de epoxy) 6-4
6.1.1.5 Remediando los reparos 6-5
6.1.2 Reparación del Acero Estructural 6-5
6.1.2.1 Elementos Estructurales de Acero 6-5
6.1.2.2 Conexiones 6-6
6.1.2.3 Reparaciones especializadas de elementos estructurales 6-7
6.1.3 Reparación de Miembros Estructurales de Madera/Leña 6-8
6.1.3.1 Orientación General de Reparos 6-8
6.1.3.2 Miembros Laminados en cola 6-9
6.2 Reparos de materiales de acabamiento de la planta 6-9
6.2.1 Materiales de Exteriores 6-9
6.2.1.1 Exteriores de madera 6-9
6.2.1.2 Exteriores de Metal 6-9
6.2.1.3 Albañilería y exteriores concretos 6-11
6.2.1.4 Exteriores de Tablero de superficie mineral 6-11
6.2.2 Materiales interiores de techo y pared 6-12
6.2.2.1 Yeso 6-12
6.2.2.2 Drywall 6-12
6.2.2.3 Losa Cerámica 6-12
6.2.2.4 Azulejo Acústico 6-12
6.2.2.5 Madera 6-12
6.2.3 Pisos 6-13
6.2.3.1 Pisos Resaltantes 6-13
6.2.3.2 Pisos de Albañilería 6-13
6.2.3.3 Pisos de Metal 6-13
6.2.3.4 Pisos sin aparencia 6-13
6.2.3.5 Pisos de madera 6-13
6.2.3.6 Alfombras 6-14
6.2.4 Tejados 6-14
6.2.4.1 Tejados pre-construidos 6-14
6.2.4.2 Tejados de Ripia de Asfalto 6-16
6.2.4.3 Tejados de Asfalto enrollado 6-16
6.2.4.4 Tejados de Cemento de Asfalto 6-16
6.2.4.5 Tejados de Metal 6-16

6.2.4.6 Tejados de Pizarra 6-17
6.2.4.7 Tejados de madera de Ripia 6-17
6.2.4.8 Tejados de Membrana Única 6-17
6.2.5 Ventanas y puertas 6-17
6.2.6 Revestimiento para superficies exteriores 6-18
6.3 Reparación de los sistemas de la planta 6-18
6.3.1 Sistemas de Distribución de Agua 6-18
6.3.1.1 Sistemas de plomería de agua natural y de desecho 6-18
6.3.1.2 Sistemas de Protección contra Incendios 6-18
6.3.2 Calefacción. ventilación y sistema de aire acondicionado 6-18
6.3.3 Sistemas Eléctricos 6-19
6.3.4 Transporte de Sistemas 6-19
6.4 Reparación de sistemas externos 6-19
6.4.1 Superficies de asfalto de caminos, calzadas 6-19
6.4.2 Salida, drenaje y sistemas de control de la erosión 6-21
6.4.3 Cercas 6-21
6.4.3.1 Remendos 6-21
6.4.3.2 Sustitución de Cercas tipo Cadena 6-22
6.4.4 Tanques 6-22

7 GESTION DEL MANTENIMIENTO DE LA PLANTA 7-1
7.1 Análisis de Reparación, reemplazo y aplazamiento 7-1
7.1.1 Factores Considerados Durante un Análisis Comprensivo 7-1
7.1.1.1 Factores cuantificables para un estudio de costo económico 7-2
7.1.1.2 Factores cualitativos importantes en el proceso de toma de decisiones 7-4
7.1.1.3 Otros factores cualitativos para consideración 7-4
7.2 Decisiones para toma de decisiones 7-6
7.2.1 Decisión para reparación de la deterioración 7-7
7.2.2 Reparación de la deterioración 7-8
7.2.2.1 Seleccionar un procedimiento de reparación 7-8
7.2.2.2 Consideraciones Adicionales de Reparación 7-9
7.2.3 Diferiendo una reparación 7-9
7.2.4 Usando contratistas y reparaciones externas 7-9
7.2.5 Evaluando la eficacia de la decisión 7-10
7.3 Métodos Alternativos de Análisis 7-10

7.4 Otros temas de Gestión de Mantenimiento de las Plantas 7-11
7.4.1 Costos de largo plazo de las plantas.....7-11
7.4.2 Camino para diseñar la información y configuración de la gestión 7-11

***8* REFERENCIAS 8-1**
8.1 Referencias en el texto 8-1
8.2 Bibliografía 8-1
8.3 Orientaciones Adicionales de EPRI pertinentes al tema 8-2
8.4 Organizaciones industriales y comerciales 8-6

***A* ELEMENTOS PROGRAMÁTICOS IMPORTANTES A-1**
A.1 Identificación y clasificación de la planta A-1
A.1.1 Tipo funcional de clasificación A-1
A.1.2 Haciendo distinción de la Propriedad Real A-1
A.2 Tipos y Prioritization de las actividades de mantenimiento A-2
A.2.1 Introducción A-2
A.2.2 Mantenimiento Reactivo A-2
A.2.3 Mantenimiento Preventivo A-2
A.2.4 Mantenimiento Predictivo A-3
A.2.5 Mantenimiento Centrado en Confiabilidad A-4
A.2.6 Mantenimiento Diferenciado A-4

***B* ESTIMATIVA DE VIDA DEL DISEÑO B-1**
B.1 Fundaciones B-1
B.2 Subestructuras B-2
B.2.1 Losas en grado B-2
B.2.2 Columnas B-2
B.3 Superstructures B-2
B.3.1 Losas y cubiertas del piso B-2
B.3.2 Escaleras B-3
B.3.3 Marco Estructural B-3
B.3.4 Paredes Estructurales Interiores B-3
B.3.5 Losas y cubiertas del piso B-3
B.4 Conclusiones Exteriores B-4
B.5 Tejados B-5
B.6 Construcciones y Acabamientos del Interior B-6

B.6.1 Paredes B-6
B.6.2 Traviesas y barandillas B-7
B.6.3 Paredes, pisos y techos B-7
B.7 Transporte de Sistemas B-8
B.8 Sistemas Mecánicos B-8
B.8.1 Tuberías B-8
B.8.2 Equipo de Protección contra Incendios B-9
B.8.3 Calefacción, ventilación y equipo de aire acondicionado B-10
B.9 Sistemas Mecánicos B-12
B.9.1 Servicio y distribución B-12
B.9.1.1 Baja Tensión B-12
B.9.1.2 Voltaje Medio B-13
B.9.2 Iluminación B-13
B.9.3 Sistemas Especiales B-13
B.10 Sistemas de Específicos B-13
B.11 Trabajo en el Sitio B-14
B.11.1 Pavimentando carreteras y caminos B-14
B.11.2 Túneles B-14
B.11.3 Cercas y puertas de seguridad B-14
B.11.4 Puentes y estribos B-14

_C_ CÓDIGOS Y ESTÁNDARES C-1
C.1 Propósito C-1
C.2 Especificaciones Federales C-2
C.3 Estándares Nacionales C-8
C.3.1 Instituto de aire acondicionado y refrigeración C-8
C.3.2 Asociación del movimiento y control de aire C-8
C.3.3 Asociación Americana de Fabricantes Arquitectónicos C-9
C.3.4 Asociación Americana de coloristas de textil y de químicos C-9
C.3.5 Instituto Americano de Concreto C-9
C.3.6 Asociación Americana de Maderas C-10
C.3.7 Instituto americano de construcción de acero C-10
C.3.8 Instituto americano de construcciones de madera C-10
C.3.9 Instituto americano de hierro y acero C-10
C.3.10 Institute Nacional Americano de Estándares C-10

C.3.11 Asociación Americana Madera Contrachapadas C-11
C.3.12 Sociedad americana para testes y materiales C-11
C.3.13 Sociedad americana de calefacción, refrigeración y de ingenieros en aire acondicionado C-18
C.3.14 Sociedad americana de ingenieros mecánicos C-19
C.3.15 Sociedad Americana de Soldadura C-19
C.3.16 Asociación Americana de los Preservadores de Madera C-19
C.3.17 Instituto de ladrillo de América C-20
C.3.18 Funcionarios de construcción y administradores del código internacional C-20
C.3.19 Instituto de acero y refuerzo al concreto C-20
C.3.20 Instituto de puerta y accesorios C-20
C.3.21 Asociación Exterior de Fabricantes de Aislamiento C-20
C.3.22 Asociación de Comercialización de Cristal Plano C-20
C.3.23 Asociación de Yeso C-21
C.3.24 Instituto de ingenieros eléctricos y electrónicos C-21
C.3.25 Asociación nacional de fabricantes e metal arquitectónico C-21
C.3.26 Asociación nacional de fabricantes de puerta de garage C-21
C.3.27 Asociación nacional de contratistas de plomería/calefacción/ventilación C-21
C.3.28 Asociación Nacional de Protección contra Incendios C-21
C.3.29 Asociación Nacional de Productos forestales C-23
C.3.30 Asociación Nacional de Madera de construcción C-23
C.3.31 Asociación Nacional de Fabricantes de Suelo de Roble C-23
C.3.32 Asociación nacional de Terrazzo y mosaico, inc.. ..... C-23
C.3.33 Asociación nacional de ventanas de madera y de puertas C-23
C.3.34 Institute de plomería e instituto de drenaje C-23
C.3.35 Asociación de Cemento de Portland C-23
C.3.36 Instituto de Concreto Pre-presionado y fabricado C-23
C.3.37 Asociación de contratistas de metal de hoja y de aire acondicionado C-24
C.3.38 Sociedad para revestimientos protectores..... C-24
C.3.39 Instituto de Puertas de Acero C-24
C.3.40 Instituto de Placas de izar C-24
C.3.41 Laboratorios de Suscriptores, Inc. C-24
C.3.42 Código Único de Construcción C-25
C.4 Publicaciones de la Industria C-25

_D_ LISTADO DE INFORMACIÓN IMPORTANTE D-1

D.1 Importantes Puntos de Costo de O&M D-1

D.2 Importantes Puntos Técnicos D-1

D.3 Importantes Puntos de Desempeño Humano D-2

LISTA DE FIGURAS

Cuadro 1-1 Integración del Guía de mantenimiento 1-4
Cuadro 2-1 Características e información de productos de material de pintura/revestimientos 2-17
Cuadro 4-1 Ventajas y beneficios de inspecciones visuales para evaluación de las Condiciones de Revestimiento 4-32
Cuadro 7-1 Factores considerados durante el proceso de toma de decisiones 7-2
Cuadro 7-2 Proceso para la Gestión de decisiones del mantenimiento de las plantas.....7-7
Cuadro 7-3 Costos de largo plazo de las plantas 7-11

LISTA DE TABLAS

Tabla 1-1 Alcance de las tablas estructuras, sistemas y componentes 1-2
Tabla 1-2 Factores de Conversión 1-9
Tabla 2-1 Resumen tabla de fuerzas 2-2
Tabla 2-2 Acabamiento de Interiores: Materiales de Pared 2-7
Tabla 2-3 Acabamiento de Interiores: Cubiertas de Pared 2-8
Tabla 2-4 Tipos de materiales de pisos y sus características relativas 2-9
Tabla 2-5 Componentes disponibles de material para techos y de componentes del material para techos 2-14
Tabla 2-6 Pinturas disponibles para exposición exterior típica del edificio 2-18
Tabla 2-7 Ventajas y desventajas de los principales materiales de construcción 2-25
Tabla 3-1 Resumen de los principales mecanismos de falla de materiales estructurales 3-3
Tabla 3-2 Mecanismos de falla para concreto reforzado 3-4
Tabla 3-3 Mecanismos de falla para acero estructural 3-6
Tabla 3-4 Mecanismos de falla para los miembros de Madera/Leña 3-7
Tabla 3-5 Imperfecciones del campo común de la en Wood/Timber 3-8
Tabla 3-6 Resistencia de decaimiento de las principales maderas 3-9
Tabla 3-7 Mecanismos comunes de falla y síntomas para varios materiales de construcción de interiores 3-12
Tabla 3-8 Mecanismos comunes de falla para los materiales de pisos 3-13
Tabla 3-9 Mecanismos de falla para los varios tipos de tejados 3-14
Tabla 3-10 Mecanismos Típicos de Falla de Bombas 3-19
Tabla 3-11 Mecanismos de falla de ventilación y sistema de exhaustor de aire 3-21
Tabla 3-12 Mecanismos de falla de los sistemas de calefacción en la construcción 3-22
Tabla 3-13 Mecanismos de Falla de los Sistemas Neumáticos 3-24
Tabla 3-14 Mecanismos de Falla de los Sistemas de Aire acondicionado 3-25
Tabla 3-15 Mecanismos de falla de componentes en sistemas eléctricos de distribución 3-27
Tabla 3-16 Mecanismos de falla de equipo de iluminación y sus causas 3-28
Tabla 3-17 Mecanismos de falla del asfalto y síntomas de deterioración 3-30
Tabla 4-1 Frecuencias de Inspección Recomendadas 4-2
Tabla 4-2 Encuesta sobre concreto existente 4-3
Tabla 4-3 Criterios de inspección para acero estructural 4-8
Tabla 4-4 Criterios de inspección para elementos de construcción de Madera/Leña 4-10

Tabla 4-5 Insectos Que Causan Daño en la madera 4-11
Tabla 4-6 Criterios de inspección para conexciones de extensión y construcción.....4-38
Tabla 4-7 Criterios de inspección para compresores de reciprocidad 4-43
Tabla 4-8 Criterios de inspección para compresores rotatorios de paletas que resbalan 4-44
Tabla 4-9 Criterios de inspección para compresores rotatorios de lóbulos gemelos 4-45
Tabla 4-10 Criterios de inspección para compresores de pistón líquidos rotatorios 4-45
Tabla 4-11 Criterios de inspección para compresores dinámicos 4-46
Tabla 4-12 Criterios de inspección para pre-enfriadores y pos-enfriadores 4-47
Tabla 4-13 Criterios de inspección para trampas 4-47
Tabla 4-14 Criterios de inspección para secadores de aire de tipo absorción 4-48
Tabla 4-15 Criterios de inspección para secadores de aire de tipo Refrigeración 4-48
Tabla 4-16 Criterios de inspección para tanques de almacenaje de gas de aire comprimido.....4-48
Tabla 4-17 Criterios de inspección para gasolina, diesel, o motores de propano 4-49
Tabla 4-18 Criterios de inspección para sistemas de distribución del vapor 4-50
Tabla 4-19 Criterios de inspección para sistemas de distribución de agua de alta temperatura.....4-51
Tabla 4-20 Criterios de inspección para instrumentos 4-52
Tabla 4-21 Criterios de inspección para controles 4-52
Tabla 4-22 Criterios de inspección para sistemas de aire acondicionado 4-53
Tabla 4-23 Criterios Inspección para componentes del sistema de iluminación 4-58
Tabla 4-24 Criterios de inspección para motores en movimiento 4-59
Tabla 4-25 Criterios de inspección para motores después de desligados 4-61
Tabla 4-26 Criterios de inspección para transformadores desenergizados 4-62
Tabla 4-27 Criterios de inspección para transformadores energizados 4-63
Tabla 5-1 Prevención de deterioración de acero estructural 5-6
Tabla 5-2 Mantenimiento de rutina recomendado para válvulas 5-25
Tabla 5-3 Mantenimiento de rutina recomendado para las bombas 5-26
Tabla 5-4 Mantenimiento de rutina recomendado para componentes del sistema de aire acondicionado 5-34
Tabla 5-5 Procedimientos comunes de mantenimiento y de reparación para interruptores 5-36
Tabla 5-6 Mantenimiento de rutina de equipo de iluminación 5-37
Tabla 5-7 Mantenimiento de rutina y procedimientos de reparación para motores ca/cd 5-38
Tabla 5-8 Mantenimiento de rutina y procedimientos de reparación para motores cd 5-38
Tabla 5-9 Mantenimiento de rutina y procedimientos de reparación para motores ca 5-40
Tabla 6-1 Reparaciones de mantenimiento para asfalto de superficies.....6-20

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