Water Control Gates

Guidelines for Inspection and Evaluation

ASCE

Water Control Gates

Guidelines for Inspection and Evaluation

Prepared by the
Task Committee on Condition Assessment of Water Control Gates
of the Hydropower Committee
of the Energy Division
of the American Society of Civil Engineers

Cosponsored by
U.S. Department of Homeland Security,
Federal Emergency Management Agency

Interagency Committee on Dam Safety

U.S. Army Corps of Engineers,
Engineer Research and Development Center

ASCE

Published by the American Society of Civil Engineers

Cataloging-in-Publication Data on file with the Library of Congress.

Published by American Society of Civil Engineers
1801 Alexander Bell Drive
Reston, Virginia, 20191-4400
www.asce.org/pubs

ISBN 978-0-7844-1220-6 (paper)
ISBN 978-0-7844-7684-0 (e-book)
Manufactured in the United States of America.

Table of Contents

This page intentionally left blank

1 Introduction

1.1 Purpose of the guide

A water resources project typically consists of a number of features that store and transport water for various purposes including flood control and navigation, domestic consumption, industrial use, irrigation, recreation, agricultural, electrical generation and other uses. Many of these purposes can only be accomplished safely and efficiently if the discharge of water is controlled by gates. Water control gates vary greatly in size, shape, operation, and purpose. They control the flow of water in small canals or over large dam spillways, in hydraulic tunnels deep inside mountains, or at the end of high pressure pipelines. This document covers water conveyance gates that control the level of a reservoir impounded by a dam.

In the United States, many of the nation's dams and waterways are older than a typical 50-year design life. As with aging structures, their appurtenant features may warrant a close look to determine their ability for continued long-term reliable safe use. This was evidenced by the 1995 failure of a large radial gate at Folsom Dam in California. In the aftermath of the Folsom incident, Federal and State regulatory agencies have increasingly expressed concern regarding the condition of radial gates in particular, and for the general condition of other types of gates as well.

In light of the 1995 Folsom incident and the resulting regulatory inquiries, the American Society of Civil Engineers (ASCE) Hydropower Committee elected to form a task committee (referred to hereafter simply as "the Committee" to disseminate information related to the evaluation of various types of water control gates commonly found in water projects. Since 1995, a variety of other incidents have occurred that have brought to light the broad nature of the types of failures that may occur. The National Performance of Dams Program (NPDP) at Stanford University in California has recorded gate incidents that have occurred throughout the United States in their database.

Starting in 2007, The Interagency Committee on Dam Safety became a partner in the development of this document. They brought additional issues into the content of the document. Their primary concern was that the information provided should consider issues faced by small organizations that own dams.

These owners are usually responsible for one or a very small number of dams. The dams themselves are also usually small and the owners may have little or no permanent professional staff to manage and maintain these dams. They are less likely to have a prescribed process for dam safety inspection and maintenance.

Dam owners hold a great deal of responsibility for the performance of their dam. Even small dams can present a risk to persons and property. It is important that owners recognize this and proactively manage the risk by taking appropriate measures, including addressing gate related issues. This document does not mandate what they must do. Instead, it is intended to help dam owners to understand what they need to consider in developing a comprehensive plan to actively manage their dam gates.

This document was written by a committee of professional engineers and other professionals representing a cross section of the water industry: owners, operators, consultants, suppliers, and regulators.

1.2 Background

To regulate the reservoir level, the discharge of water in all operational conditions must be safely controlled at all times. To do this, various types of hydraulic gates may be employed, the size and type of which depends on their particular function. The selection of gate type is based largely on reliability and economics, i.e., what can be used in a particular situation with the lowest cost and greatest reliability to achieve the desired operational characteristics. For example, radial gates are often installed on dam spillways, where pressures are low and discharge regulation can be cost-effectively achieved due to their light weight, versatility, and ease of operation. Conversely, heavy slide gates often control the flow in pressure tunnels and dam sluiceways where the pressures are higher, but where the flow regulation is not as sensitive.

In general, few catastrophic failures of water control gates have been recorded. This is probably because failure of typical water control gates (medium to small sized) have not historically produced significant threats to public safety. Although relatively few incidents have been recorded, the root causes of most of these gate incidents seems to have been problems with operating mechanisms, lack of maintenance, general deterioration or fatigue, unusual loading conditions not included in the design (such as debris, heavy snow, or ice), or operational (human) errors.

1.3 Scope of the document

The purpose of this document is to provide a useful guide of information and engineering techniques for inspecting and evaluating water control gates commonly found at water resources projects. The design of these gates has evolved over many years of practice. Projects of different ages show different design concepts and features. This document is intended to bring together in one reference basic information pertinent to evaluating the most common types of water control gates that have been used throughout the last century in the United States. It is not intended to go into depth on various engineering theories and techniques that can be employed to design, inspect, or evaluate a water control gate, but will aid the reader in understanding the basic functions of various gates and their associated operating mechanisms. Specific references are provided to aid readers in their search should more in depth knowledge be needed. In addition to the specific references, this document includes an extensive bibliography.

The document is organized by various subject matters into nine chapters and supplemental information:

- Chapter 1 introduces the subject and discusses the need and purpose of the document.
- Chapter 2 describes various water control gates and operating systems.
- Chapter 3 provides basic information on operation of gates.
- Chapter 4 supplies basic information on maintenance of gates.
- Chapter 5 gives background information on how to prepare for a gate inspection.
- Chapter 6 outlines how detailed visual gate inspections should be performed.
- Chapter 7 gives information on inspection of gate operating systems.
- Chapter 8 provides guidance in gate system testing.
- Chapter 9 describes how the evaluation process is done.
- Appendix A provides example inspection checklists.
- Appendix B lists example procedures for inspection and testing.
- Appendix C covers crane inspection.
- Appendix D is calculations for determining curvilinear water pressure on a gate face.
- Appendix E provides PMF examples.
- References and bibliography are gathered at the end.

Note that most water control gates are located in environments that constitute hazardous working conditions (i.e., tunnels, flumes, canals, dam spillways, low level outlets, etc.). For that reason, the reader is strongly urged to review appropriate Federal, state, and local laws governing the safe conduct of working at heights, in confined spaces, on electrical components, and other safety concerns. Rules and regulations from organizations such as OSHA (Occupational Safety and Health Administration), FERC (Federal Energy Regulatory Commission), SPRAT (Society of Professional Rope Access Techniques), and state and local safety agencies should be strictly followed at all times. The owner, supervisor, engineer, or responsible person in charge should be certain that every precaution is taken to protect the safety of workers involved in the job.

1.4 Definition of terms

For the purposes of this document, the following are some general terms and their meanings, as defined by the Committee:

- **Inspection**. The act of carefully examining or officially reviewing a certain detail or phenomenon. Inspection includes measurements and observations to identify equipment misoperation; inoperable, distressed, misaligned, damaged, missing, corroded, worn components; etc. A gate inspection may include an operational test.
- **Examination**. The act of looking at critically or methodically investigating to gain knowledge about certain details or phenomenon. It is common to compare actual conditions with design drawings and specifications.
- **Evaluation**. An all-encompassing term used to describe the process of using the data obtained in an inspection or examination, performing analyses, and determining the acceptability of a water control gate. The evaluation will typically include tasks dealing with data, stress analysis, and comparisons with defined acceptance criteria to determine suitability.
- **Gate system**. The entire system that includes the water control gate; its support structures; or the frame, operating system, and seals.
- **Water control gate**. A structure that can be used in such a manner to block or regulate the flow of water over or through a water retaining or conveyance structure or system.
- **Gate operating system**. The mechanism or system used to adjust and mechanically and electrically control the position of a gate.

- **Qualified inspector**. An individual with appropriate, documented skills and knowledge for a particular examination or official review.
- **Head**. The height of water to the free water surface held behind a dam, gate, or other barrier.

1.5 Referenced standards

While the most recent versions of standards, codes and manuals have been cited, as new versions are published these should be referred to for the current standard of practice.

1.6 Participating organizations

The following organizations provided support in the development of this document. Their participation is gratefully acknowledged:

- California Department of Water Resources, Division of Safety of Dams, Sacramento, CA
- Chelan County Public Utility District, Wenatchee, WA
- Enel North America Inc., Andover, MA
- Federal Energy Regulatory Commission, Washington, DC
- Crane Tech, Aledo, TX
- HDR Engineering, Omaha, NE
- JEFFCO Painting and Coating, Vallejo, CA
- Kleinschmidt Associates, Pittsfield, ME
- Knight Piésold Consulting
- Mead and Hunt, Inc., Madison, WI
- MWH Americas, Inc., Chicago, IL
- Northrop Engineering Corporation, Falmouth, ME
- Pacific Gas and Electric Company, San Francisco, CA
- Southern California Edison, San Dimas, CA
- Southern Company Services, Atlanta, GA
- Steel-Fab, Fitchburg, MA
- Structural Integrity Associates, San Jose, CA
- Tennessee Valley Authority, Chattanooga, TN
- U.S. Army Corps of Engineers, Hydraulic Design Center, Portland, OR
- U.S. Army Corps of Engineers, Engineering Research and Development Center, Champaign, IL
- U.S. Bureau of Reclamation, Denver, CO.
- WD Edwards Consulting, Novato, CA
- Xcel Energy, Eau Claire, WI.

1.7 The original task committee

The following individuals constitute the Task Committee membership responsible for developing the document.

- Charles S. Ahlgren, Pacific Gas and Electric Company, San Francisco, CA (ASCE Task Committee Chairman)
- William H. Allerton, Federal Energy Regulatory Commission, Washington, DC
- Louis Bartolini, Steel-Fab, Fitchburg, MA
- Norman A. Bishop, Knight Piésold Consulting, Chicago, IL
- L. G. Byrnes, Southern Company Services, Atlanta, GA
- William Christman, Chelan County Public Utility District, Wenatchee, WA
- Wayne Edwards, WD Edwards Consulting, Novato, CA
- Victor Engel, Enel North America, Inc., Andover, MA
- Stuart Foltz, U.S. Army Corps of Engineers, Champaign, IL
- David Gutierrez, California Department of Water Resources, Division of Safety of Dams, Sacramento, CA
- Kim Hansen, Mead and Hunt, Madison, WI
- Peter Hoffman, U.S. Bureau of Reclamation, Denver, CO
- Jerry Joy, U.S. Army Corps of Engineers, Portland, OR
- Thomas L. Kahl, Kleinschmidt Associates, Pittsfield, ME
- Scott Kramer, Tennessee Valley Authority, Chattanooga, TN
- Richard A. Mattson, Structural Integrity Associates, San Jose, CA
- Michael Morgan, MWH Americas, Inc., Chicago, IL
- William McStraw, U.S. Bureau of Reclamation, Denver, CO
- Vikram Negi, MWH Americas, Inc., Chicago, IL
- John Northrop, Northrop Engineering Corporation, Falmouth, ME
- Richard Rudolph, Xcel Energy, Eau Claire, WI
- Chander Sehgal, MWH Americas, Inc., Chicago, IL
- Paul Sutherland, Southern California Edison, San Dimas, CA
- Richard Warriner, Aledo, TX.

1.8 Reformulated committee

From approximately 2002 until 2007, the ASCE sub-committee developing this document was largely inactive. Little or no progress was made towards completion of the document. Based upon a proposal submitted by U.S. Army Corps of Engineers (USACE) to the Interagency Committee on Dam Safety, the Federal Emergency Management Agency (FEMA) provided funds to USACE incrementally in 2007-2010 for development of a publication with a scope similar to the inactive ASCE effort. With the concurrence of FEMA, the USACE project manager and ASCE agreed to work towards a joint publication. A formal agreement was signed in July 2007. The reformulated committee included the following individuals:

- William H. Allerton, Federal Energy Regulatory Commission, Washington, DC
- Louis Bartolini, Steel-Fab, Fitchburg, MA
- Norman A. Bishop, Knight Piésold Consulting, Naperville, IL
- William Christman, Chelan County Public Utility District, Wenatchee, WA
- Wayne Edwards, WD Edwards Consulting (formerly with HDR Engineering), Oakland, CA
- Stuart Foltz, U.S. Army Corps of Engineers, Champaign, IL (USACE/ASCE/FEMA Committee Chairman)
- Kim Hansen, Mead and Hunt, Madison, WI
- Thomas L. Kahl, Kleinschmidt Associates, Pittsfield, ME
- Scott Kramer, Tennessee Valley Authority, Chattanooga, TN
- John Northrop, Northrop Engineering Corporation, Falmouth, ME
- Richard Rudolph, (Retired) Xcel Energy, Eau Claire, WI
- Richard Warriner, Aledo, TX.

1.9 Interim reviews and blue ribbon committee review

During the fall of 2007, the draft document was sent to four individuals including three from state dam safety organizations. The primary objective was for them to assess the applicability of this guideline to small organizations that own dams, looking for gaps and suggesting how the document could be made more useful to the small owner. Their suggestions have been incorporated.

State-level reviewers included:

- Mike P. Evans, International Boundary Water Commission
- Ed Fiegle, State of Georgia dam safety
- Mike Lowe, Lower Colorado River Authority
- James Robinson, State of Virginia dam safety.

During the spring of 2009, Ronald Branam (TVA) offered to perform a review of our draft document. He made substantial contributions in text and photos in many chapters throughout the document.

The final peer review by a Blue Ribbon Committee was completed during the summer of 2010. Blue Ribbon committee reviewers included:

- David Blanchette, SM&RC Structural Engineers, Inc.
- John Farmer, TVA
- Charles Hatcher, Knight Piesold Consulting
- Bruce McCracken, USACE
- Bernard Peters (retired), USBR
- Sam Planck, HDR Engineering, Inc
- James Robinson (retired), State of Virginia Dam Safety
- David Schaaf, U.S. Army Corps of Engineers
- Chander Sehgal, MWH Americas, Inc., Chicago, IL
- Richard Stutsman, Consultant
- John Yale, Chelan County Public Utility District

As the ASCE Hydropower Committee Chair, Mario Finis provided a review of the final draft.

1.10 Acknowledgments

This document was prepared under the supervision of the American Society of Civil Engineers, Energy Division, Hydropower Committee, the Interagency Committee on Dam Safety, and the Federal Emergency Management Agency. A need for information and guidance in inspecting and evaluating water control gates, which was initially expressed to the ASCE Committee in the spring of 1998, served as the original impetus for preparation of these guidelines. The Interagency Committee on Dam Safety subsequently and independently expressed a similar need.

I wish to thank the Task Committee Members, Reformulated Committee Members, interim reviewers, and Blue Ribbon Committee reviewers for their tireless efforts in making the document a success. Those individuals and organizations most directly responsible for the development and publication of the guidelines were noted earlier. The Reformulated Committee members hope that this document will assist the water industry in the inspection and evaluation of water control gates.

STUART FOLTZ
Chairman, Reformulated Committee on
Guidelines for Evaluation of Water Control Gates

2 Gate Descriptions and Operating Systems

2.1 Introduction

This chapter describes the types of gates and gate operating systems commonly in use to control the release of water. For each type of gate and operating system, there are many variations suitable for the specific site conditions and operating requirements. Emphasis is placed on the most common components and aspects of gate systems. The objective was to focus on custom fabricated gates. There are other types of standard design water control gates and valves that are not covered.

2.2 Description of gates

2.2.1 General function and application

The function of a water control gate is to control the flow of water through a conduit or opening. A particular gate may be used to perform one or more of the following functions:

- **Regulating**. Regulating gates are generally operated quite frequently and are used to throttle and vary the rate of discharge through a conduit or opening by varying the effective flow area. Common applications include low level outlets and bypass conduits. These gates can be operated under high pressure and flow conditions. Some spillway type gates are also used as regulating gates. Typically radial and hinged crest gates are positioned on the top of a spillway and act as a movable crest to regulate the water level and provide necessary downstream flows.
- **Flood control**. Flood control gates are usually located on spillways and are designed to pass large amounts of water around or over the dam structure. These gates are generally used less frequently and pass large amounts of water during flood events, usually by bypassing the primary water conduits. They are also used in high flow, run of river applications. Low level outlet gates may also be used for flood control.
- **Emergency closure**. Emergency gates are meant to be operated under emergency conditions and can be closed under full water pressure and flow to protect equipment downstream. These gates are also called guard

gates and are normally designed to operate fully opened or fully closed as a secondary device for shutting off the flow of water in case the primary closure device becomes inoperable.

- **Maintenance and dewatering**. Dewatering and maintenance closures are typically used under planned, balanced head conditions to shut off flow and allow for dewatering of a conduit or water passage to enable inspection and maintenance operations in a dry condition. The most common closures used are slide gates, bulkheads, and stoplogs. Gates specifically designed for this purpose typically do not have dedicated hoists. Emergency closure gates may also be used for this purpose.

Table 2-1 lists common uses of the most common gate types. The following sections describe the various gate types.

2.2.2 Basic gate features

Numerous types of gates are currently in operation throughout the world. There are a multitude of shapes and sizes, but their design usually incorporates the basic components shown in Figure 2-1.

The basic components of a gate include:

- **Skinplate**. The skinplate forms a barrier to retain and support the water load. The term 'plate' can be somewhat misleading because the plate could be a steel plate section, a wooden member (such as flash boards or wooden head gates), or a rubber or vinyl fabric (such as an inflatable gate). The skinplate is in direct contact with the water and is usually not strong enough to withstand hydraulic forces by itself and therefore requires a means of structural support to transmit the loads to the supporting structure.
- **Structural framing**. The skinplate is typically supported by a system of ribs, girders, struts, and/or stiffeners that convey the hydraulic loads to the support structure, usually consisting of the dam monoliths or spillway piers. The type and arrangement of the structural framing forms the major differences between gate types. The support structure typically consists of steel, but can also consist of timber, concrete, or air pressure (in the case of inflatable dams).
- **Anchorage**. The anchorage is the assembly that supports the gate and transfers the load from the structural framing members to the support structure, usually a concrete pier. Some types of gates do not use

anchorages, but rather directly transfer the hydraulic loads to the support structure by bearing (e.g., slide and wheel gates). Concrete anchorages for trunnions, and hinge and torque tube bearings have many different configurations. These can include concrete and post-tensioned concrete anchors. In some cases, there will be embedment of a steel beam or girder.

Table 2-1. Gate types and most common uses.

Type of Gate	Page	Regulating	Flood Control	Emergency Closure	Maintenance/ Dewatering
Bulkhead/Stoplog	18			●	●
Drum	21	●	●		
Hinged Crest	24	●	●		
Flashboards	28		●		
Navigation Wicket	33	●			
Floating Bulkhead (Caisson)	38				●
Inflatable	40	●	●		
Radial (Tainter)	44	●	●		
Roller Dam	45	●	●		
Wheel and Roller Mounted Types	49				
Wheel Mounted	50	●	●	●	●
Roller Mounted (Caterpillar/Coaster)	50	●	●	●	●
Paradox	50			●	●
Ring Seal	55			●	●
Stoney	56			●	●
Vertical Lift Slide	57	●		●	●
Bonneted	57	●		●	●
Jet-flow (bonneted)	60	●			
Ring Follower (bonneted)	62			●	●
Sluice	65	●	●	●	●
Bear Trap	67		●		
Clamshell	69	●			
Cylinder	70	●	●	●	
Ring (morning glory inlet)	74	●	●		
Fuse	74		●		

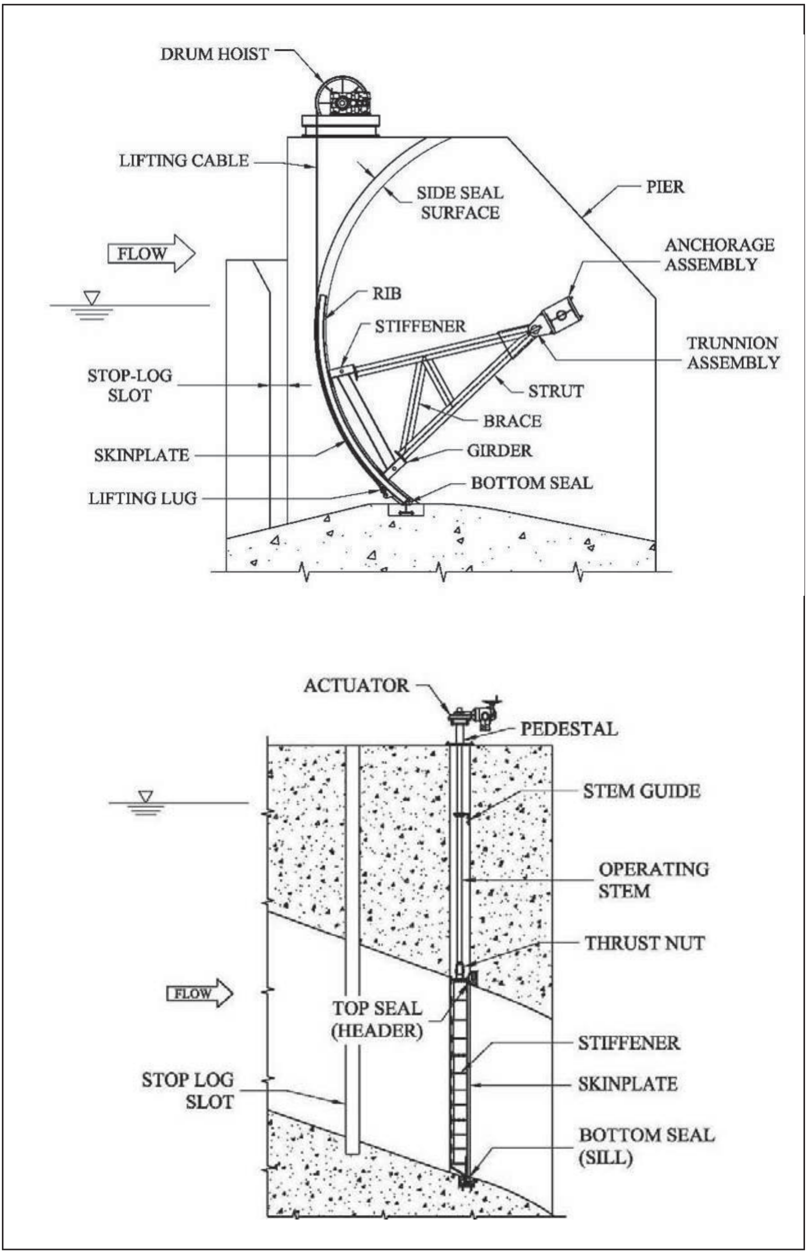


Figure 2-1. Basic gate components.

- **Embedded parts.** Embedded parts are usually parts embedded in concrete to form the gate bearing and sealing surfaces. They usually include side bearing and sealing plates, bottom (sill) sealing and bearing plates, and, in the case of top sealing gates, top (lintel) sealing plates. Usually the exposed faces of the embedded parts for long design life gates are made of stainless steel, as the embedded parts are difficult to access for maintenance or replacement.
- **Seals**. The interface between gate and the water conduit or opening is often equipped with a sealing system to minimize leakage through the gaps. Some sealing systems are only functional when the gate is in the fully closed position, others must also retain part of their sealing function when the gate is moving to prevent vibration or spray. Seals can either be flexible or rigid depending on the type of gate and its environment. Section 2.5 includes a sample of the variety of seals used on water control gates.
- **Operating mechanism**. Typically, gates are passive structures that require some means of external actuation to either raise, lower, or rotate them open or close. This is accomplished through the use of some type of a mechanical hoist or hydraulic/pneumatic actuators. These operating mechanisms must be capable of moving the gate throughout the full range of travel under possible loading conditions. Operating mechanisms can be either fixed in place (and are therefore fully dedicated to a particular gate) or mobile (and are used to operate multiple gates). Section 2.6 describes types of operating mechanisms.
- **Electrical**. The operating mechanism may have manual operation but, except for the smallest gates, primary power will be electric. Electric power may be available from an on-site powerhouse and from one or more external power lines. On-site power will typically come from a substation or voltage transformer through feeder cables. Engine-generators may also provide backup power.
- **Controls**. Electrically operated gates will have controls located at the gate, on a service bridge, a project office, the powerhouse, and/or an off-site headquarters. Small gates may be hand operated and some electric powered gates may have hand operated backup.

2.3 Gate materials

2.3.1 General

Gates are typically designed to be as efficient as possible with respect to weight versus strength. This reduces the cost of the gate and minimizes the required capacity of the gate operating system. Gates are typically constructed from a structural grade metal, concrete, or timber, or a combination of these. These materials provide the structural rigidity to enable a gate to withstand and transfer forces applied by the water to the surrounding concrete structure. One exception to this rule is an inflatable gate, such as a rubber dam, which is constructed from a reinforced rubber compound filled with air or water. In this case, the combination of the rubber and compressed fluid provides the structural means necessary to transfer the hydrostatic load to the surrounding concrete structure.

2.3.2 Material standards and codes

The structural material used on a gate structure can usually be identified from an as-built drawing, original project specifications or design calculations. Materials are typically identified by a Standard or Specification designation that can be referenced to obtain chemical composition and strength characteristics. Material standards have been formalized by various organizations throughout the world and generally provide the information needed to determine material properties. These standards are periodically updated; therefore, when it comes to analyzing older gate structures, current material standards may not list the characteristics of older steels. In this case, the engineer may have to contact the relevant Standards organization to obtain information on older materials. The following U.S. organizations provide material designations used in the industry:

Metals
ASTM – American Society for Testing and Materials
AISI – American Standards Institute
SAE – Society of Automotive Engineers

Timber
AITC – American Institute of Timber Construction
AWC – American Wood Council
ASTM – American Society for Testing and Materials

Several other national and proprietary standards also reference material and strength characteristics. Lastly, the material properties may be listed in the design documents, referenced by basic composition numbers and level of heat treating.

Numerous foreign countries publish and reference their own material standards, similar to the above American standards. A complete list of these organizations is beyond the scope of this document. Many existing publications cross-reference international material standard designations with the American standard designations; one such publication is published by ASM International Worldwide Guide to Equivalent Irons and Steels.

If no material specification can be obtained from design documents, then a metallurgical examination may have to be performed. By performing a chemical and strength analysis of a material sample, the necessary characteristics can be accurately determined. There are numerous testing laboratories around the United States and the world that routinely perform such analyses.

2.3.3 Connections

The methods used to connect various components of a gate include bolting, welding, and riveting. Riveting was used extensively in the past, but was seldom used after the 1960s. Bolting and welding are currently the most widely used means of connecting. These common connectors are characterized by:

- **Bolts**. As with structural steel, bolt materials are available with a large range of capacities. Structural bolt material specifications can most readily be found in ASTM standards as defined above. The design of bolted connections is most commonly governed by the American Institute of Steel Construction (AISC), which provides allowable capacities of structural grade bolts. Stainless steel bolts are often used where disassembly is necessary for maintenance.
- **Welds**. Welding is a process that joins materials by fusion. Weld metal is deposited to join the parts. There are numerous types of weld metals used in present day construction, depending on the types of materials being joined and by the weld process being used. The American Welding Society (AWS) lists the weld materials to be used for various base materials. The weld metal is typically selected to match or exceed the strength properties of the base material.
- **Rivets**. The use of rivets in current practice is almost unheard of due to the labor intensive nature of the process. Riveted construction was prevalent before the 1960s and is therefore found on several of the older gates designed before that period. The earlier AISC specifications list the

material properties and permissible strength of rivet materials. The ASME Boiler and Pressure Vessel Code covers rivets in detail.

2.3.4 Bushing materials

Bearing applications for gates typically involve high load at slow rpm. On older gate installations, steel and bronze bushings were predominantly used. Grease fittings were installed on the outside of each bearing to inject lubricant into circumferential grooves machined around the inside diameter of the bushing. Not all older gate trunnions have lubrication capability. To reduce maintenance by eliminating separate greasing systems, self-lubricating bronze, composite and polytetrafluoroethylene (PTFE) Teflon® lined bushings were developed to replace the older traditional greased bushings. All of these types are still in use today.

In some cases, designers used an O-ring or bushing seal to prevent moisture or debris from entering the contact surfaces of the bushing and pin or axle. The O-ring or bushing seal is metal, rubber or a plastic material. Upon inspection the O-ring or bushing seal is often found missing, and the gates have been operational.

2.3.4.1 Steel

Cold rolled and forged steel bars were the first generation of bearing material used for gate applications and are still used today. Generally both material types require an external lubrication system to keep the bearing lubricated and to prevent corrosion. There are applications where no provisions for lubrication were made.

2.3.4.2 Bronze

Copper based solid bronze materials are used instead of steel bushings given their resistance to corrosion and lower coefficient of friction. However, a lubrication system is still required to provide the external lubrication needed for the bearing to function properly over time.

2.3.4.3 Self-lubricating bronze

This type of bushing was developed to resolve previous bearing lubrication problems by using permanent solid lubricant inserts on the inside surface of the bearing for continual and uniform lubrication. The lubricant inserts protrude from the inside diameter of the bushing and at first rotation will fill asperities on the shaft to form a good interface between the bearing and shaft. In addition to the elimination of maintenance concerns, self-lubricating bronze bushings provide a lower coefficient of friction than conventional bronze bushings.

2.3.4.4 Composites

Composed of solid sacrificial material made up of phenolic (plastic) resins and fibrous materials, composite materials have lower allowable bearing pressures than metallic bearings and are difficult to contain when press fit. These materials are not well suited for the high bearing pressures found in larger gate applications.

2.3.4.5 PTFE Teflon®

This material is commonly used as a liners on the inside diameter of some composite bearings to reduce the coefficient of friction. The chemical name polytetrafluoroethylene (PTFE) is a synthetic fluoropolymer that is best known by the DuPont™ trade name Teflon®. These materials, like composites, should be attached to the backing metal plates by countersunk screws or bolts, and are also, in most cases not suitable for high bearing pressures.

2.3.5 Seal materials

Flexible gate seals must exhibit high tensile strength, high tear resistance, abrasion resistance, low water absorption, and resistance to aging. The current rubber compound used (which meets the above requirements) consists of natural rubber (approximately 70% by volume) and reinforcing carbon black, zinc oxide, accelerators, antioxidants, vulcanizing agents, and plasticizers. The tensile strength of this rubber material ranges between 2,500 and 3,000 psi with durometer hardness between 60 and 70 (Shore type A). This combination produces adequate strength while maintaining flexibility. For very low head gates, durometer hardness 50 (Shore type A) is sometimes used to increase seal flexibility. Refer to ASTM spec D2240.

Rigid gate seals are mounted either by welding, bolting, or "dovetailing" to the surrounding steel gate or embedded part material. The softer material is designed for removal and replacement as it will wear over time.

- **Bronze to stainless steel**. Bronze, the softer of the two materials, is typically provided on the gate leaf, which is normally more accessible for maintenance and/or seal replacement.
- **Stainless steel to stainless steel**. Used only when the two surfaces do not slide against one another such as bottom seals on tainter gates. Many USACE navigation projects that feature tainter spillway gates use a stainless tapered edge profile at the bottom of the gate and seal against an embedded stainless steel plate.
- **Stainless steel to Babbitt (lead)**. Normally provided as bottom seals for high-pressure bonneted slide gates. The bottom edge of the gate is usually knife edged and is made of stainless steel and the seating surface, which is integral with the gate frame and flush with the water passage, is made of babbitt.
- **Ultra high molecular weight polymer (UHMWP) or polytetrafluoroethylene (Teflon®) to stainless steel/bronze**. This is becoming more common on newer gates and in rehabilitation of existing slide gates.
- **Timber to concrete or steel**. Used on older gate systems and operated under balanced head.

The specifications for the above seal material arrangements vary depending on design criteria including bearing strength, wear resistance, hardness, material compatibility, and friction. The materials used are typically provided on the manufacturer's shop drawings.

2.4 Description of gate types

Gates in operation today have many design variations and differences based on the unique circumstances associated with their application. In general, gates can be categorized into a number of common and less common types. The following sections describe these types of gates.

2.4.1 Bulkheads and stoplogs

Bulkheads and stoplogs are probably the simplest and most common gate types, typically made from steel, concrete, or timber. They may be used in conduits such as in Figure 2-2 and in open channel waterways such as spillways. These gates are typically used for maintenance purposes and are typically placed and removed under balanced head conditions. Although they typically are not designed for installation under flow conditions, in some circumstances bulkheads or stoplogs are used for emergency

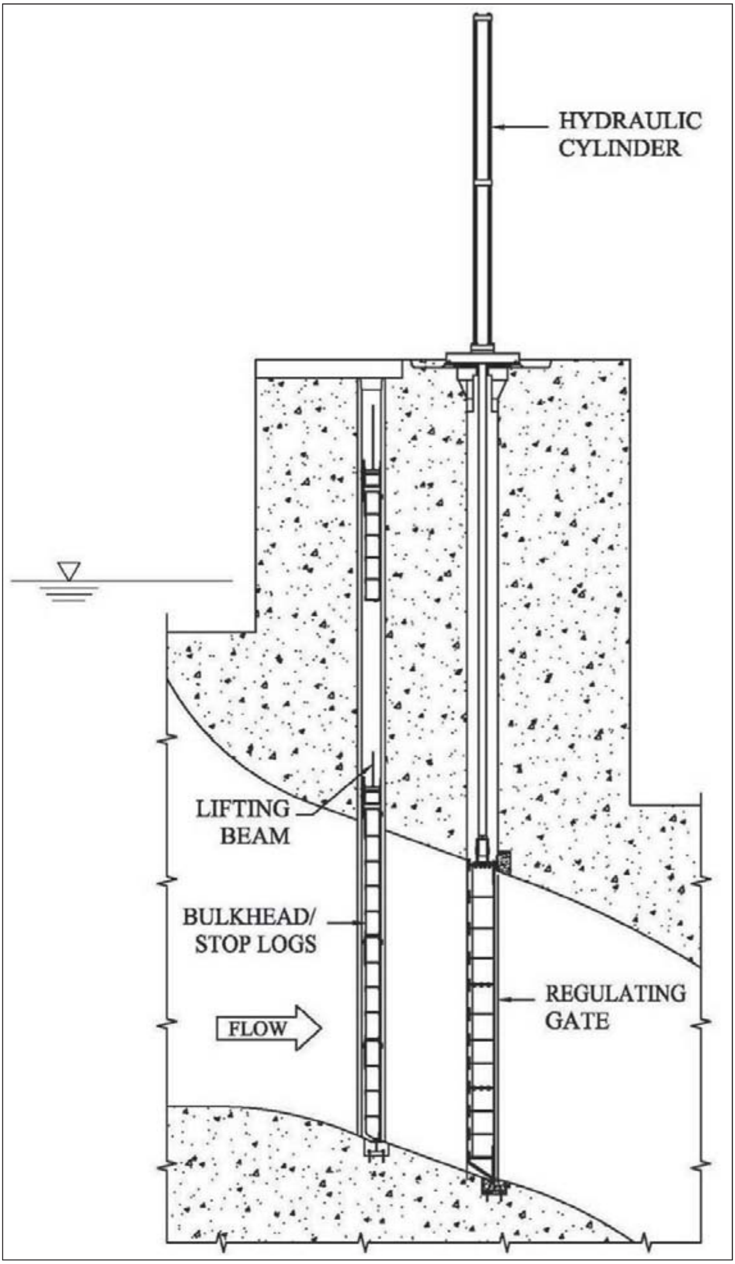


Figure 2-2. Bulkhead/stoplog.

situations where no other closure option is available. The most common type of bulkhead is made from steel since its strength-to-weight ratio is high. A steel bulkhead typically consists of a skinplate supported by multiple steel beams and stiffeners that support the hydrostatic forces. The end of each beam is connected to a continuous vertical end member. The end members transfer the hydrostatic forces from the beams to the water passage perimeter over the entire height (or width). Bulkheads are normally equipped with rubber seals around the perimeter that seal against the opening of the water passage. A bulkhead normally slides down slots via guiding devices, or may be manually guided into place at the face of the water passage opening.

Bulkheads can be provided in a single section or in multiple sections depending on clearance restrictions and handling equipment capacity limitations. Multiple section bulkheads are usually called "stoplogs" (Figure 2-3). The term stoplog, in its original form, refers to one of a series of timber panels or logs placed horizontally on top of one another in a vertical slot to close off a water passage. The original term has carried over to multiple section steel bulkheads that are also placed in sections on top of one another with a hoisting device. Each section is constructed in very much the same way as the single piece bulkhead described above. The bulkheads/stoplogs may be downstream sealing or upstream sealing. The more advanced styles are provided with a rubber seal on the bottom and a flat steel sealing surface on the top of each section that form a substantially watertight seal between stoplog sections when stacked together. Alignment devices (dowels or pins) are often provided to properly orient each newly placed section with the section below for proper sealing.

Bulkheads and stoplogs are usually placed by means of a mobile lifting device such as a gantry crane, monorail hoist, or mobile crane. Depending on the application, the bulkhead or stoplog may be manually handled with slings or may use a more elaborate device such as a semi-automatic lifting beam (Figure 2-3) that permits automatic attachment/detachment of the bulkhead/stoplog (Figure 2-4) for placement/removal. Some bulkheads are equipped with filling valve(s), to fill the area downstream for balancing the head across the bulkhead to equalize the water pressure before removing.

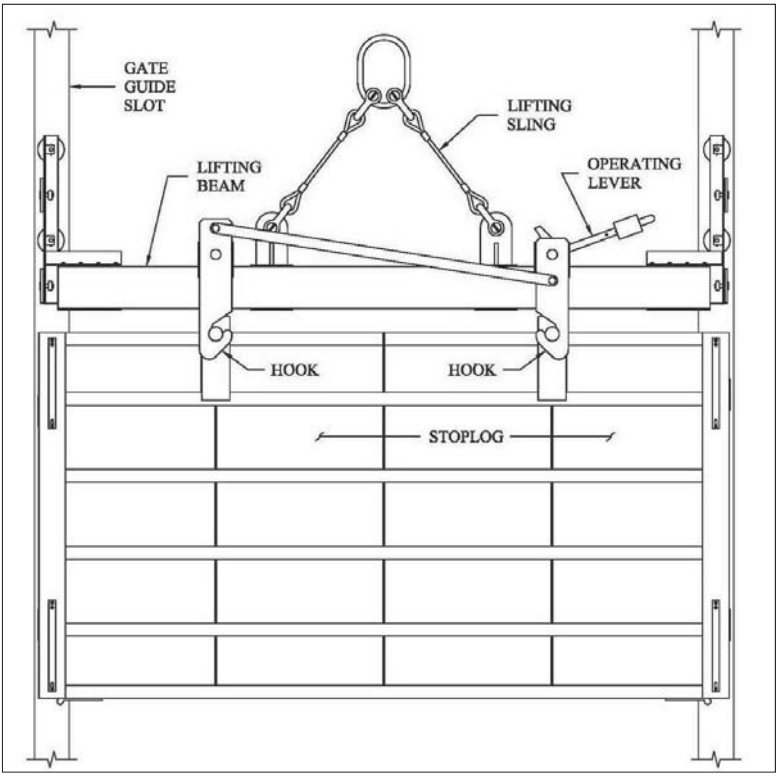


Figure 2-3. Stoplog with lifting beam.

2.4.2 Drum gate

Drum gates are used as crest gates on spillways to regulate water levels. A drum gate (Figures 2-5 and 2-6) is essentially a horizontally orientated, sealed, floating drum that is operated using the principle of buoyancy. The drum is constructed as an acute circular sector in cross section, formed by skinplates reinforced with internal bracing. The drum is hinged at the center of curvature, which may be orientated on the upstream or downstream side, in such manner that the entire gate may be raised above the fixed spillway crest to block the water passage or may be lowered into a dedicated alcove (also called a control chamber) below the crest. The hinge or hinge point and its embedment into the concrete are a critical feature. When in the fully lowered position, the drum surface becomes essentially flush with the spillway crest and covers the alcove, leaving an unobstructed flow path.

Figure 2-4. Stoplogs.

The drum gate is operated by the application of headwater pressure beneath the gate. When the gate is to be raised, the dedicated alcove is filled with water from the headwater side. The gate weight is overcome by buoyancy and the gate is forced to rise. Conversely, to lower the gate, water is drained from the alcove.

Flow into and out of the alcove is controlled by a manually operated or automatically controlled valve system. The gate must seal off the alcove (that is at headwater pressure) and the perimeter of the water passage. Rubber seals are normally used for this gate type.

Figure 2-5 shows the two principal arrangements of this type of gate. The top illustration shows an upstream hinged drum gate enclosed on three faces (downstream skinplate and ends) to form a substantially watertight vessel. The bottom illustration shows a downstream hinged gate that is usually enclosed only on the upstream and downstream surfaces.

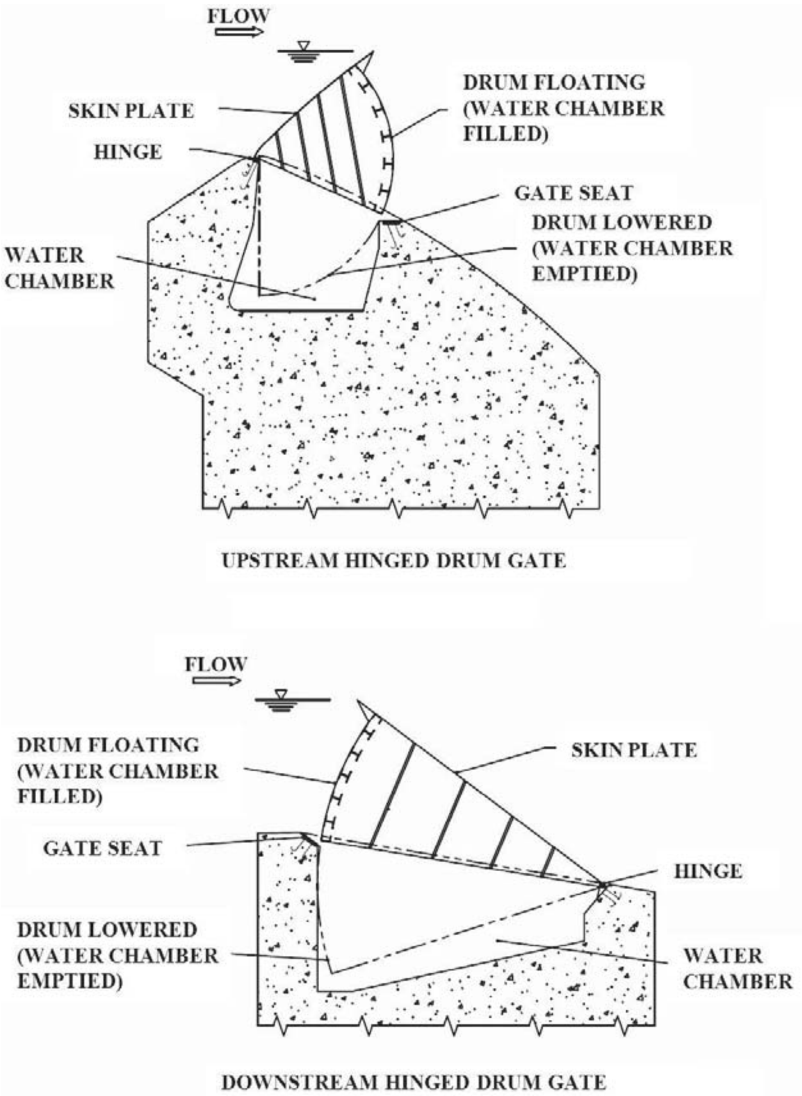


Figure 2-5. Drum gate.

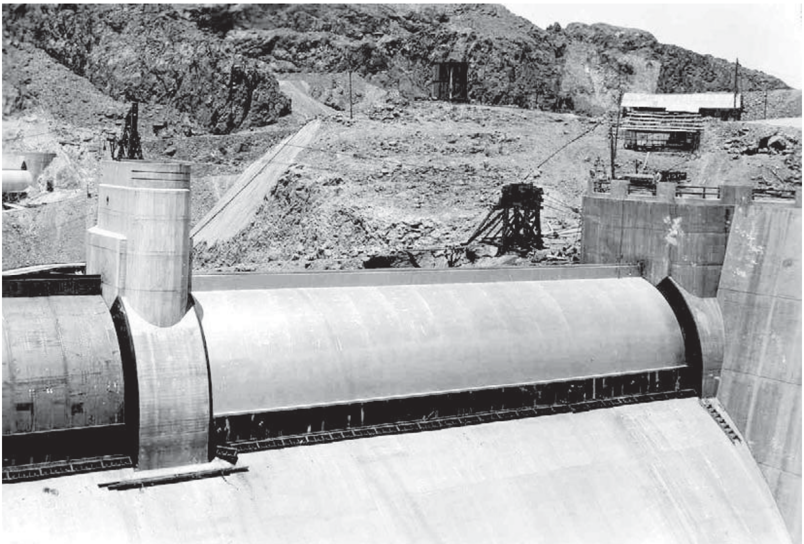


Figure 2-6. Drum gate in raised position (Courtesy of USBR).

2.4.3 Hinged crest gate

Hinged crest gates are installed on the crest of a spillway and are used to regulate water levels and sluice trash and ice. A hinged crest gate consists of a reinforced steel leaf, hinged along the bottom edge about a horizontal rotation axis. The gates are opened and closed by rotating the gate leaf down and up (respectively) about these hinges. In the lowered position, the gate leaf conforms to the profile of the spillway crest. Two main types of hinged crest gates have been designed based on the method in which the rotational torque to operate the gates is achieved: (1) the standard hinged crest gate (referred to as a fish belly gate based on their structural configuration), and (2) the torque tube type gate. Figure 2-7 shows both types of gates.

The standard hinged crest gate consists of a reinforced gate leaf hinged to the crest of the spillway using multiple low friction bearings. The hinge points or torque tube bearing points and their embedment into the concrete are a critical feature. Some hinged crest gates may not have a torque tube. The gate leaf is either a reinforced single skinplate (Figure 2-8) or a reinforced double skinplate design (Figure 2-9 and Figure 2-10). The double skinplate style gate provides added torsional rigidity and is used on gates of longer widths.

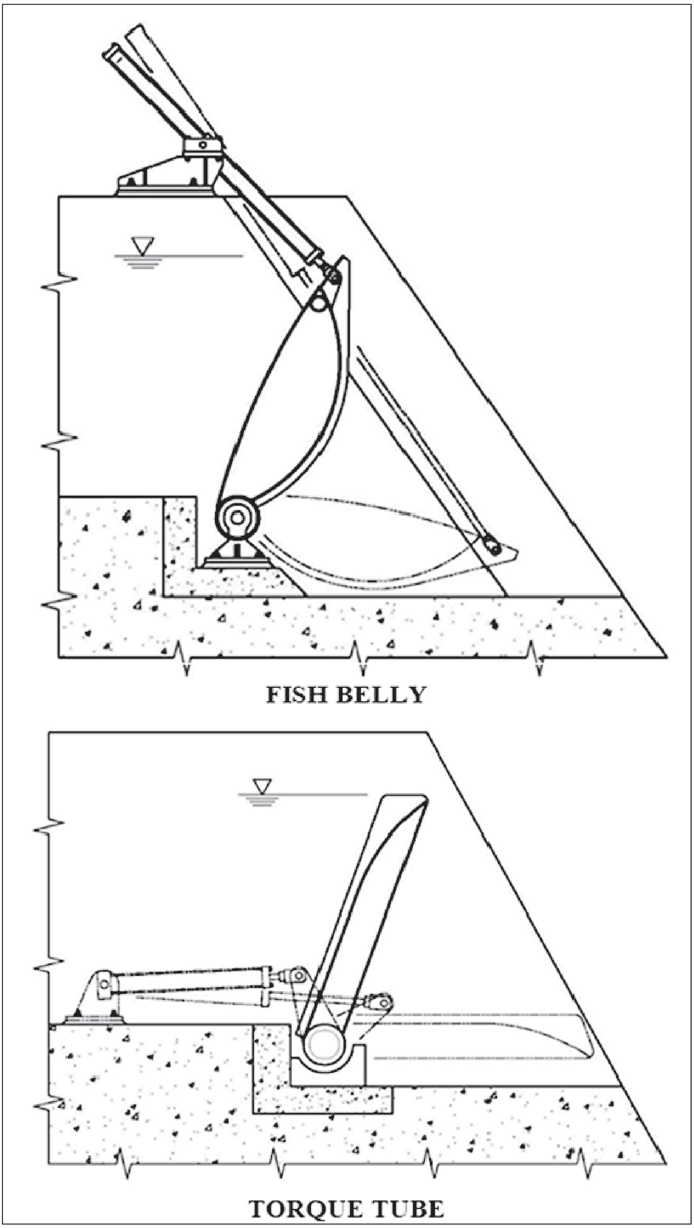


Figure 2-7. Hinged crest gates.

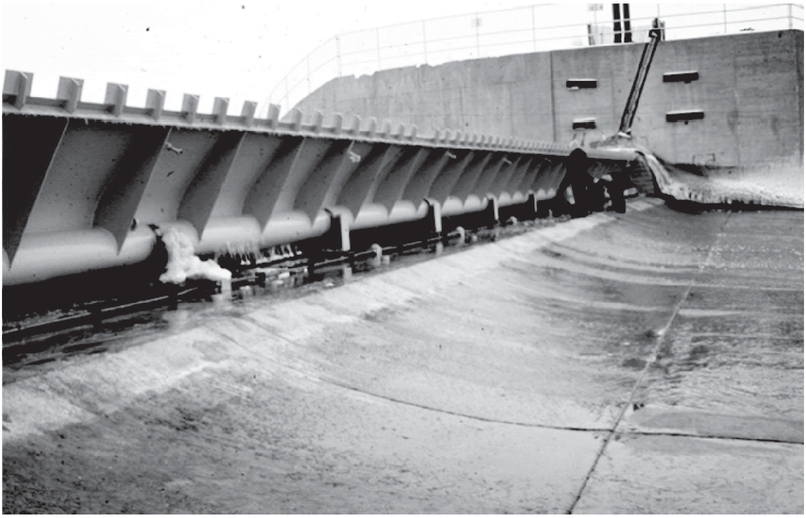


Figure 2-8. Single skinplate torque tube hinged crest gate (Courtesy of USBR).

Figure 2-9. Double skinplate torque tube hinged crest gate.

The operating equipment for standard hinged crest gates is typically multiple hydraulic cylinders placed either on the downstream side of the gate under the gate leaf or hydraulic cylinders attached to the gate leaf at or near the top of the leaf with the cylinders mounted on the adjacent piers. Depending on the width of the gates, several hydraulic cylinders mounted on the downstream side may be used across the width of the gate opening to reduce the torsion on the gate leaf. However, downstream mounted cylinders are subject to damage by trash in water passing over partially open hinged crest gates.

Figure 2-10. Double skinplate torque tube hinged crest gate.

The torque-tube crest gate uses a structural round tube with a leaf extension (Figure 2-8). The axis of the tube is coincident with the rotational axis of the gate and the tube is supported by multiple saddle bearings or hinges placed along its length. Main vertical girders extend from the torque tube to support the gate skinplate. The leaf can be either flat or curved depending on the geometry of the spillway. The gate is raised or lowered by applying a torque to the torque tube to operate the gate. This is commonly accomplished using hydraulic cylinders attached to a crank mechanism affixed to the tube either at one or both ends of the torque tube. The hydraulic cylinder, crank mechanism, and operating system are usually installed in a vault in the concrete pier adjacent to the gate.

The seals for hinged crest gates are rubber, located along the axis of rotation and are placed at the hinge points and at the sides of the gate leaf for a substantially watertight seal.

2.4.4 Flashboards

Flashboard systems are typically used to temporarily extend the height of the impoundment and retain water to a predetermined level. They may also be used to direct flow to a particular portion of the spillway, whether that is to direct irrigation water where it is needed or for advantageous channel conditions. There are many types of flashboard systems including hinged, pinned, propped, stanchion, fixed frame, and needle beam systems. These systems are typically composed of a series of timber planks positioned side by side or stacked and supported by different means on top of an impounding structure or spillway crest. In a flood event, the flashboards can be designed for quick removal, manual trip, or to fail automatically when the water level rises to a predetermined level.

Hinged flashboards (Figure 2-11) act as primitive hinged crest gates and consist of a timber or steel panel, hinged to the crest at the bottom and propped on the downstream side by a strut. The prop is either manually tripped externally or is designed to buckle at a predetermined force (corresponding to a certain water level on the panel) to collapse the prop. Since the panels are attached to the crest, they are not washed away and can be reset after the flood event and propped again in position.

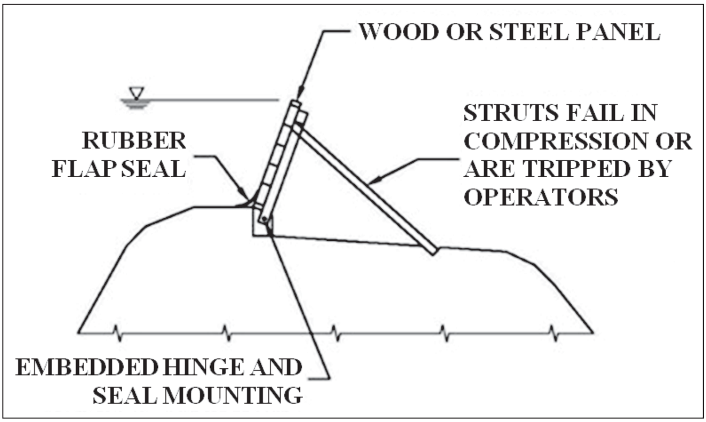


Figure 2-11. Hinged flashboards.

Pinned (Figures 2-12 and 2-13) and propped flashboard systems (Figure 2-14) can be typically designed to fail completely once the water level reaches a predetermined elevation or in other cases when top support pins are removed. Both systems are equipped with "weak link" supports (vertical pin supports in the case of a pinned type flashboard and strut (prop) in the case of a propped type flashboard) that will fail once loaded beyond a critical point by water pressure on the flashboards. For these systems, the flashboard panels are typically washed downstream.

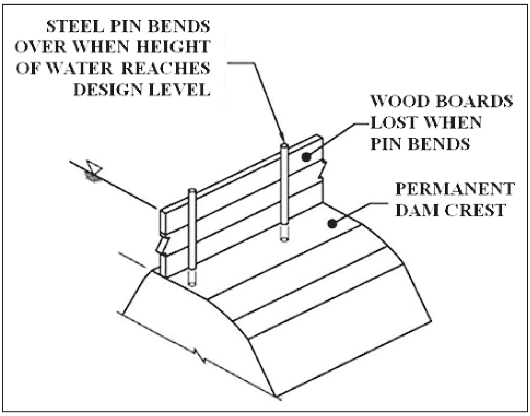


Figure 2-12. Pin type flashboards.

Figure 2-13. Installation of pinned flashboards.

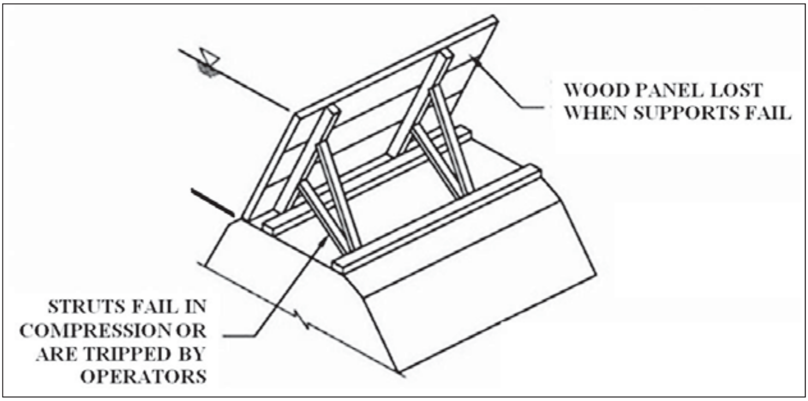


Figure 2-14. Propped flashboards.

A stanchion type flashboard system (Figure 2-15) consists of timber planks positioned within vertical guide support members. The support members typically consist of vertical H-pile sections which pivot near the top so as to rotate when jacked or tripped and allow the planks to separate and wash downstream.

Some flashboard systems consist of steel frames permanently attached to the spillway crest (Figure 2-16). Wooden flashboards are manually installed in vertical frame members to increase reservoir storage in the summer. The boards are removed in the winter to provide spillway capacity to pass floods. In some parts of the country this type of flashboard system may be called stoplogs.

The last type of flashboard system is a needle dam or needle beams (Figure 2-17). This system is composed of vertically orientated flashboards, supported at the bottom by a notched bearing surface at the crest and at the top by a horizontal beam that spans the width of the water passage. To pass flood water, the needles are removed by lifting each one from its seat. The needles are retained and reset later.

2.4.5 Navigation wicket gates

Wicket gates are used in conjunction with navigation lock projects to maintain the navigation water levels during periods of lower flow. During low flow periods the wickets are raised to increase the water level and navigation traffic

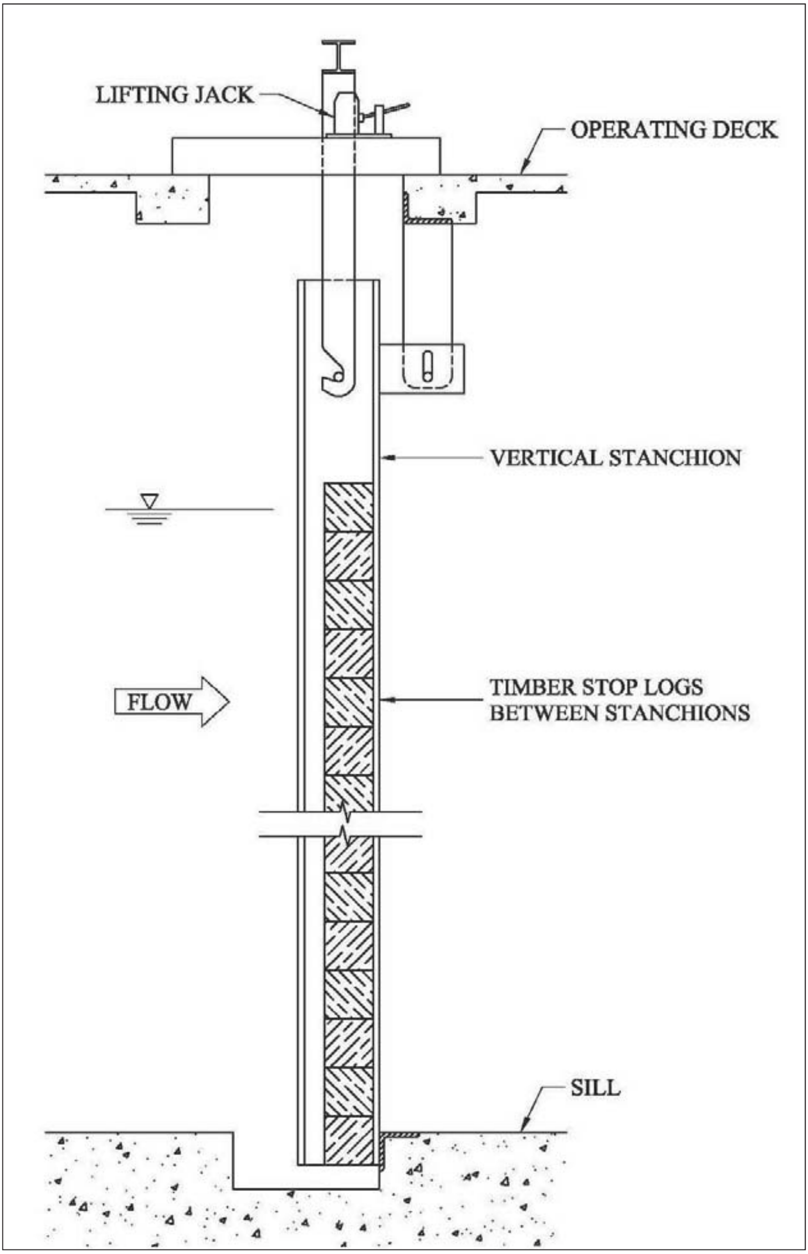


Figure 2-15. Stanchion flashboards.

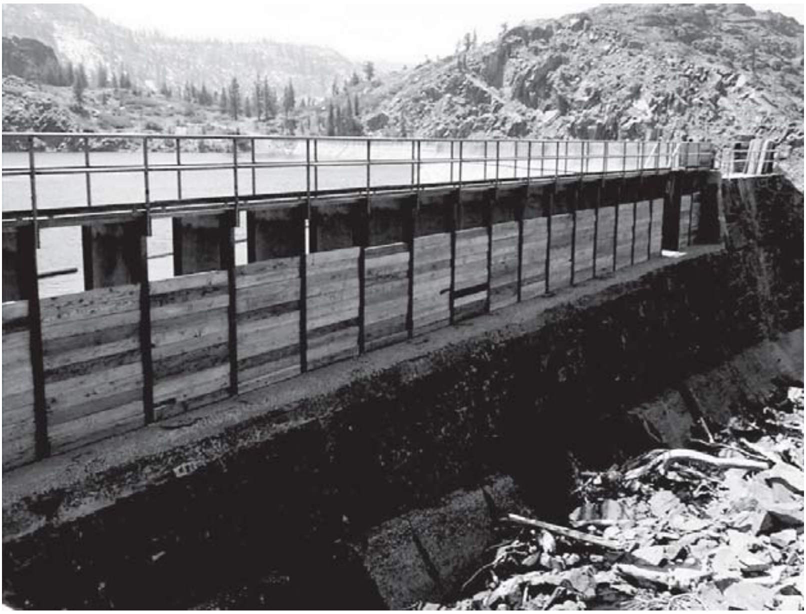


Figure 2-16. Fixed frame flashboards.

is routed through the companion lock. In periods of higher flow and water levels, the wickets can be lowered to allow higher flow to pass unrestricted and river traffic may be able to bypass the lock.

2.4.6 Navigation wicket gates

Wicket gates are used in conjunction with navigation lock projects to maintain the navigation water levels during periods of lower flow. During low flow periods the wickets are raised to increase the water level and navigation traffic is routed through the companion lock. In periods of higher flow and water levels, the wickets can be lowered to allow higher flow to pass unrestricted and river traffic may be able to bypass the lock.

Numerous wicket designs have been developed throughout the years. Conventional wicket gates (Figure 2-18) consist of four major components: A flat impounding surface (wicket); a steel support frame (also known as horse frame), a prop, and a hurter. Operation of manually set wicket gates is a labor intensive process performed from a floating platform (Figure 2-19). To raise a conventional wicket off the bottom of a river, a boat is maneuvered along the

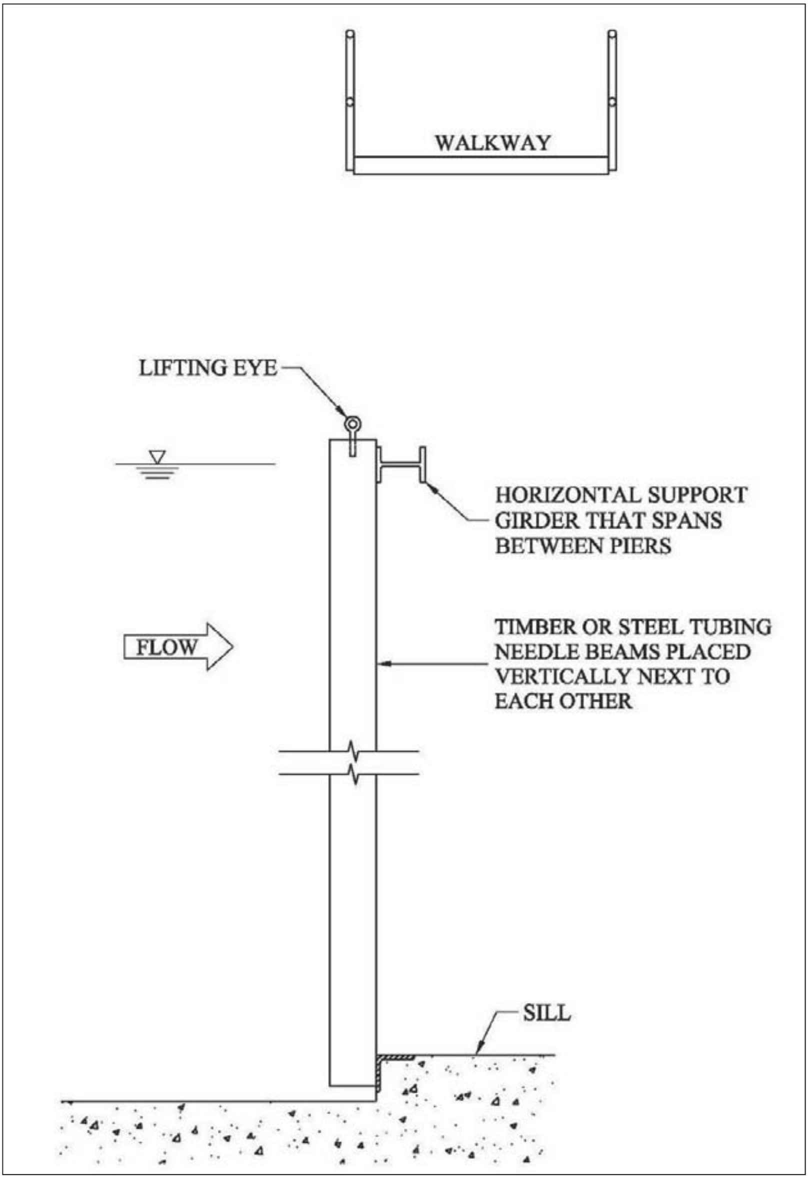


Figure 2-17. Needle beam system.

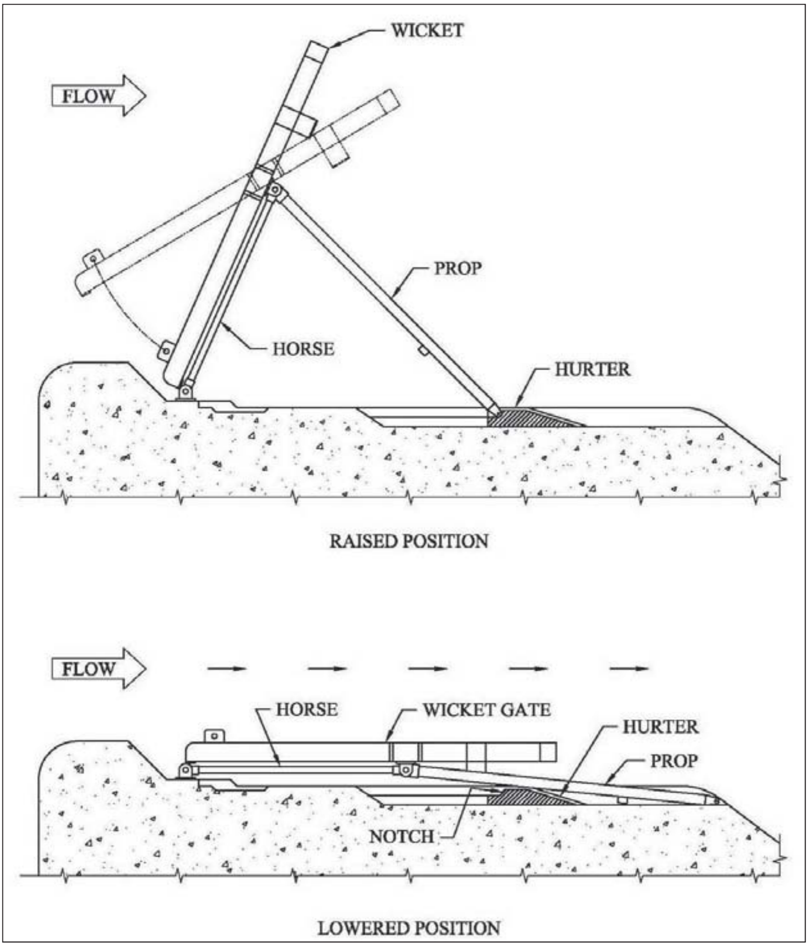


Figure 2-18. Conventional wicket gate.

dam and a hook is lowered into the river, which connects to a pin located on the bottom or upstream end of the wicket. A winch then raises the wicket, horse frame and prop. The prop is guided along a groove in the sill of the dam also called a hurter. The hurter has a notch, which, when the gate is fully raised, retains the prop, securing the wicket and horse frame in position. Once the prop is set the wicket gate is pivoted around the horse frame and current holds the wicket in a raised position, typically 60 deg. To release a wicket and lower it back to the river bottom, a boat again maneuvers along the face of the dam and a hook is attached to the top of the wicket. The wicket is then pulled

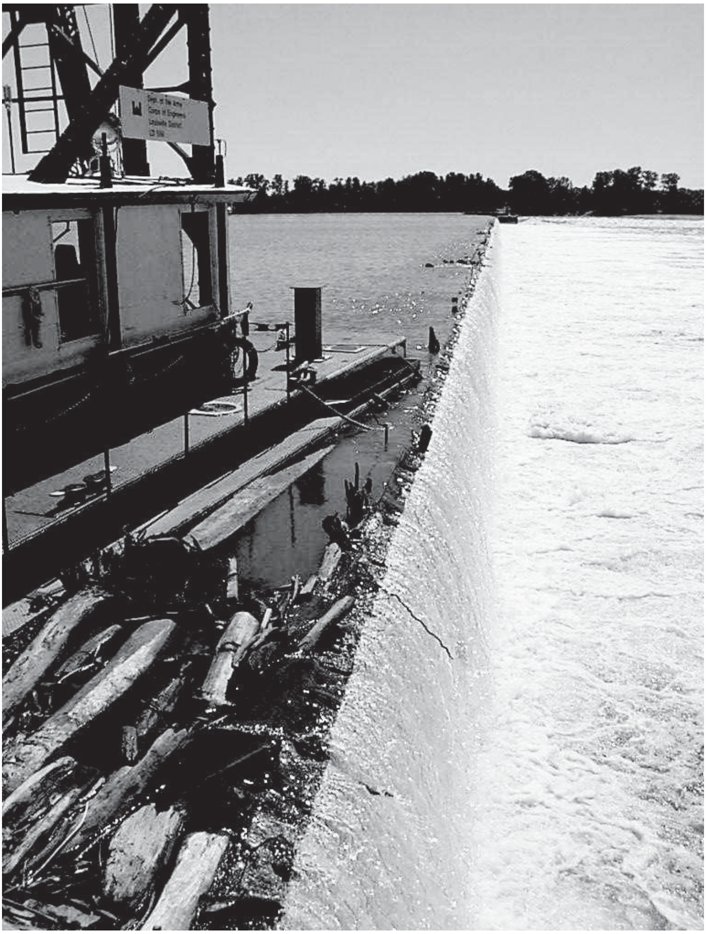


Figure 2-19. Wicket gates (manual placement type)
(Courtesy of USACE).

forward upstream and the prop lifts out of the notch in the hurter. A guide directs the prop around the notch in the hurter once it is raised beyond a certain point. Current and gravity then lower the wicket to the bottom. Original wickets were made of white oak timbers and steel frames. Modern wickets are steel frame structures, the latest of which use the same principles as conventional designs. A new automated hydraulic operated wicket gate has been designed and tested and is shown in Figures 2-20 and 2-21. Two different designs have been developed, direct connected and retractable. They

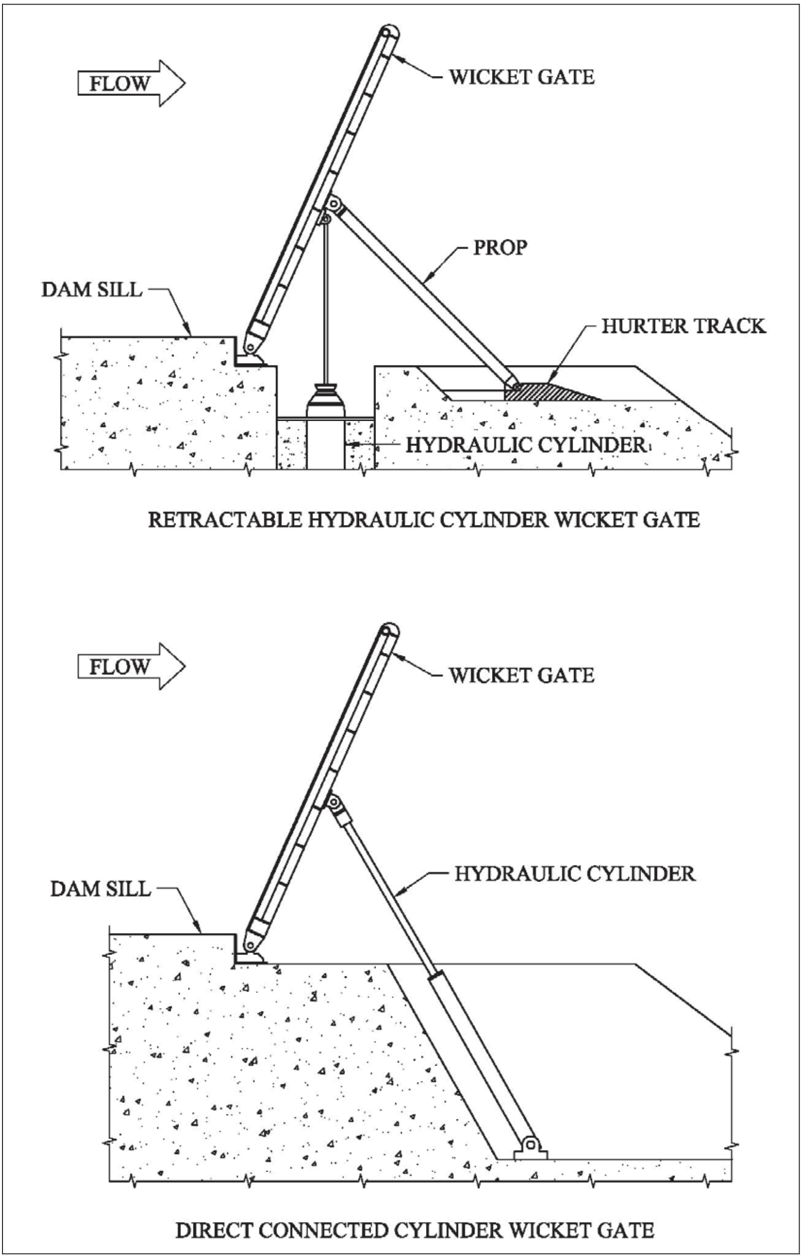


Figure 2-20. Hydraulically actuated wicket gate.

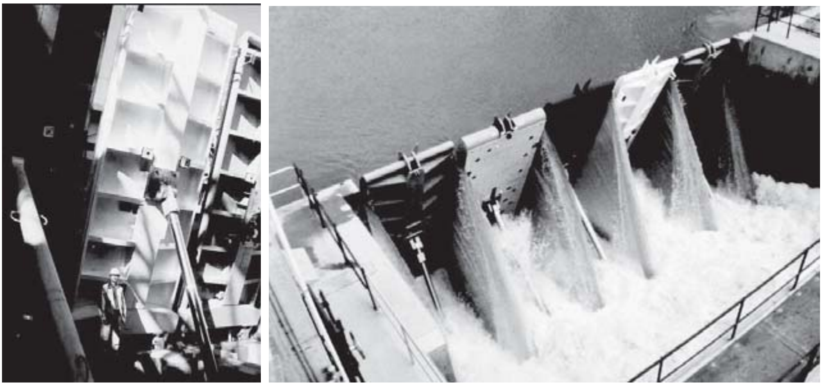


Figure 2-21. Hydraulically actuated wicket gates
(Courtesy of USACE).

both incorporate a hydraulic cylinder mounted under the gate to raise and lower a wicket.

2.4.7 Floating bulkhead (caisson)

Floating bulkheads (sometimes referred to as floating caissons) are steel bulkhead type gates completely enclosed on all sides by skinplates and are equipped with integral ballast chambers that can be filled with water or pressurized with air. Ballast chambers act as the means to raise and lower the bulkhead via buoyancy. These bulkheads are typically floated in front of an opening, sunk into position, and raised using buoyancy, thereby eliminating the need for large external hoisting equipment (Figure 2-22). The bulkhead is placed and removed under balanced head conditions and seals against the face of a dam or piers or against an embedded steel sealing frame. The bulkhead is seated to sealing surfaces once a differential head is created. Floating bulkheads may be one piece or hinged multi-piece, and can be constructed to very large dimensions because they need not be raised with external hoisting equipment. They can be used to service many gate bays because they are easily moved. Figure 2-23 shows a single-piece floating bulkhead being positioned.

Floating bulkheads have been constructed in many shapes and sizes and can be equipped with pump equipment to empty ballast compartments and dewater the water passage. Floating bulkheads have been designed to permit a means of access from the water surface into the dewatered water passage.

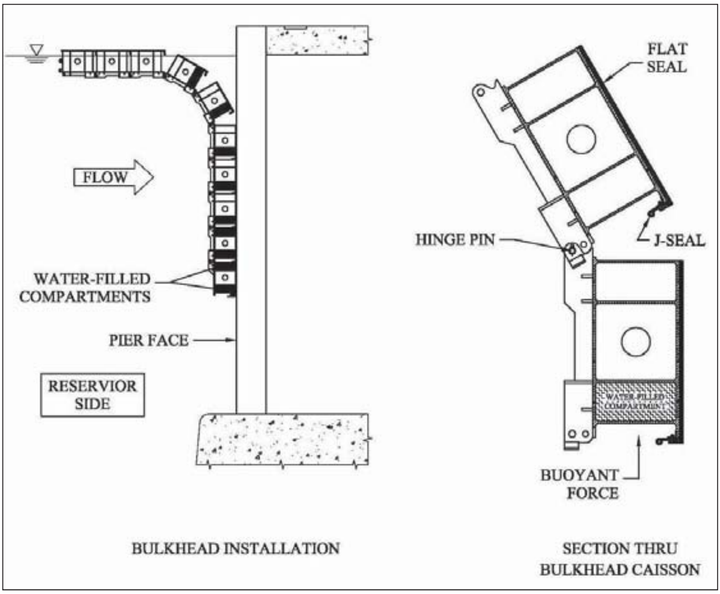


Figure 2-22. Articulated floating bulkhead.


Figure 2-23. Single-piece floating bulkhead being positioned.

Figure 2-24. Articulated floating bulkhead, installed.

Articulating bulkheads (Figures 2-22 and 2-24) are a more recent development and are growing in popularity because they can be floated horizontally into position in front of an opening, with minimal draft, submerging into vertical position in front of a water passage.

Floating bulkheads typically use conventional sealing systems like those used on bulkheads/stoplogs. In some cases, however, the sealing system may require special design considerations to seal against rough concrete surfaces. Special seal design considerations could include concrete surface repairs, inflatable seals, flap seals, membranes, sealing strips, etc.

2.4.8 Inflatable gate

Inflatable gates are used on crests of spillways, dams, or other water passage as a means to temporarily raise the hydraulic height of the structure on which it is installed. The inflatable gate uses an inflatable rubber bladder to perform this function. Single gates have been designed to very large widths, and are often used to maintain the water elevation or sluice debris and ice. The two commonly used types of inflatable gates are the rubber dam and the steel faced inflatable gate.

A rubber dam (Figures 2-25 and 2-26) consists of a tubular, inflatable bladder made of a single, or multi-layered synthetic fiber fabric, rubberized on one or both sides or coated with plastic film. The bladder is anchored to the spillway crest at the upstream edge and at the side walls. This is accomplished by a series of anchor bolts and plates clamping the folded edges and ends of the bladder together. Pressurized air or water is used to expand the bladder to form an impoundment structure. Within limits, changing the pressure in the

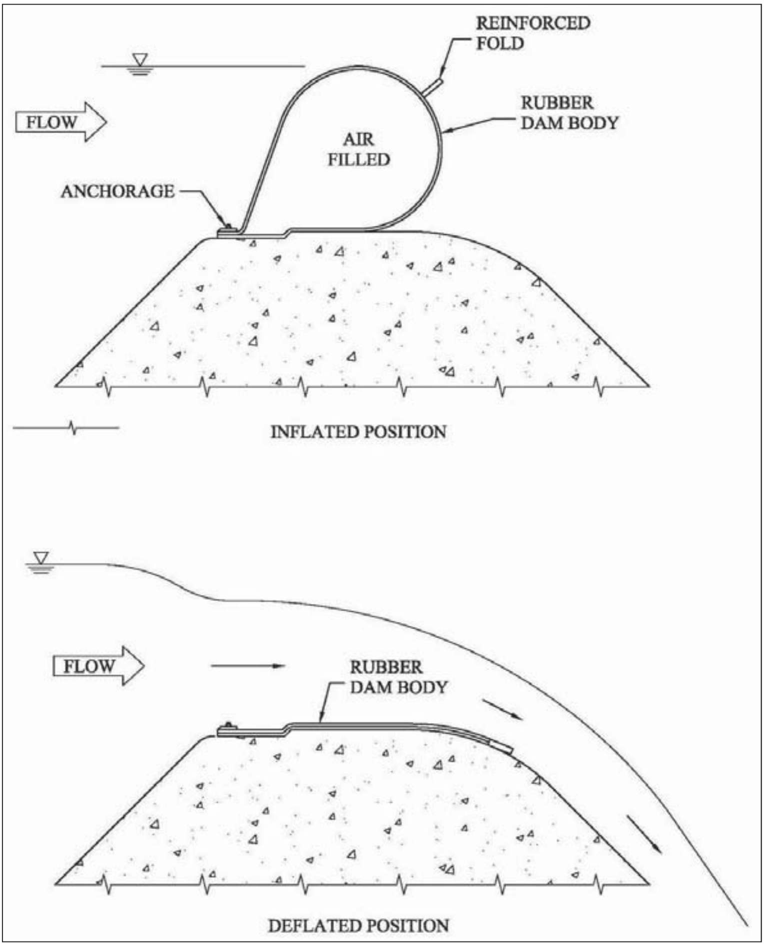


Figure 2-25. Rubber dam function.

Figure 2-26. Rubber dam.

bladder can change its height and control the upstream water level. When deflated, the rubber bladder flattens against the crest of the spillway.

A steel-faced inflatable gate (Figure 2-27) consists of a tubular rubber bladder supporting a straight or arced pivoting steel plate. Both the rubber bladder and steel plate are secured to the spillway crest via a clamping/pivot assembly. The rubber bladder is located on the downstream side of the steel plate and is inflated/deflated to rotate the steel plate upward/downward. The bladder is inflated/deflated in a similar manner as the rubber dams described above. The steel plate is typically equipped with vertical ribs for structural rigidity, as seen in Figure 2-28. Rubber restraining straps attached between the top of the steel plate and the ogee crest structure are used to prevent over-rotation of the steel plates. Typical installations consist of multiple steel plate leaves supported by one or more bladder sections. The steel-faced inflatable gate can be segmented and used on a very wide waterway such as a river channel.

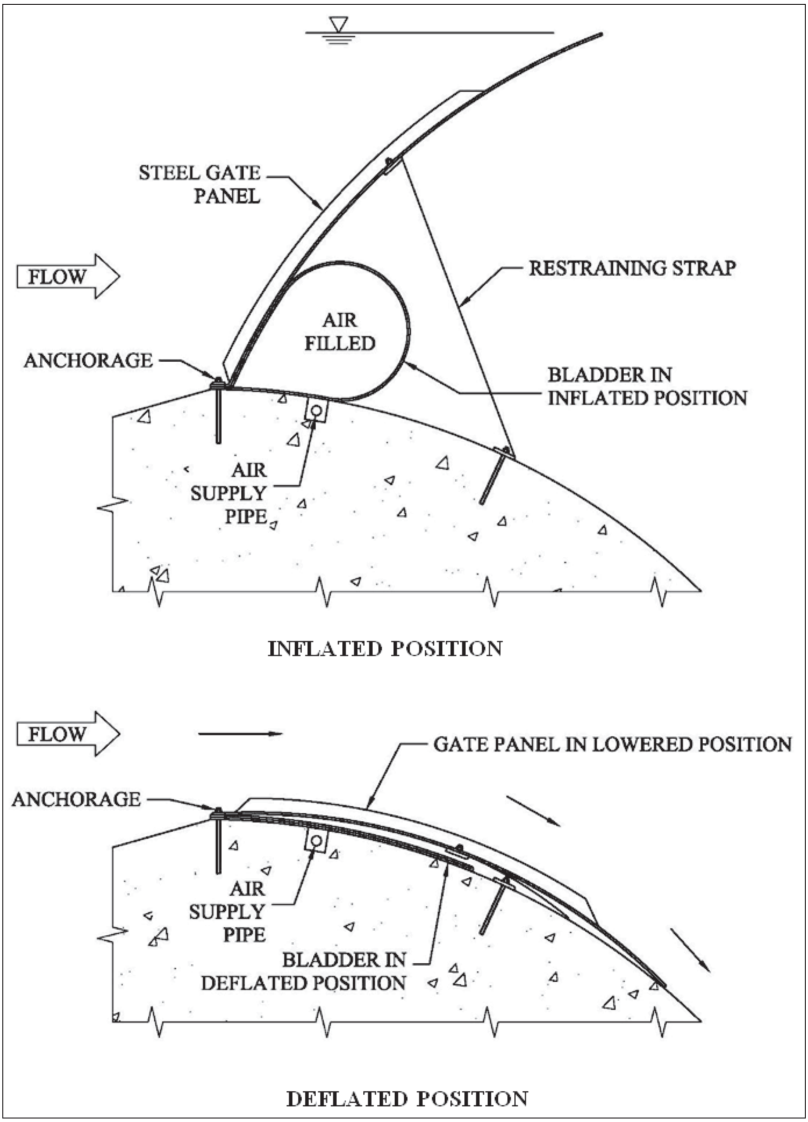


Figure 2-27. Steel-faced inflatable gate.

Figure 2-28. Steel-faced inflatable gate (Courtesy of USBR).

2.4.9 Radial (tainter) gate

Radial gates, also referred to as tainter gates, are the most commonly used flood control gates due to their simplicity and efficient design. Although most commonly used as free surface spillway gates, radial gates are also used in orifice applications. The radial gate skinplate is oriented similar to a segment of a horizontally aligned cylinder. The upstream water pressure is typically applied to the convex side of the circular segment. The downstream side of the skinplate is reinforced by stiffening ribs and supported by main girders orientated either horizontally or vertically. The main girders, in turn, are supported near each side of the gate by two or more radial struts (arms) that converge to the axis of rotation of the skinplate. Trunnions, consisting of rotating horizontal pins anchored into the mass concrete of the spillway piers are located at the points of convergence of the struts. The resultant thrust of the water pressure acts radially through the axis of rotation of the trunnions. Since the gate pivots about this point, the resultant trunnion friction moment to be overcome by the operating mechanism is small because of the radius ratio of pin radius over skinplate radius.

Radial gate hoisting equipment must overcome four loads; weight of gate, side seal friction, water pressure on the bottom seal extension, (upstream of the skinplate), and trunnion pin friction moment. Side seal and trunnion friction are a function of water pressure and sealing surface conditions.

The manner in which the radial gate structure accommodates hydraulic forces and the normal position of the operating equipment with lifting elements on the upstream side of the skinplate generally results in the smallest hoisting capacity for operating machinery when compared to the other types of common gate. Therefore, radial gates may be designed larger than other types of vertical lift gates for the same hoisting capacity.

Normally radial gates are sealed at the bottom and at the sides against embedded plates flush with the floor and wall surfaces of the gate bay, usually with flexible rubber seals. Some radial gates have side rollers to keep the gate centered. This reduces binding, seal friction, and damage. For orifice type radial gates a top seal is mounted on the lintel and seals across the entire width of the gate leaf skinplate over the full range of gate raising to eliminate flow over the top of the gate leaf during gate operation.

The operating machinery for radial gates is located above the gate and typically includes wire rope hoists, chain hoists, or hydraulic cylinders. Wire rope and chain hoists are usually attached to lifting lugs near the bottom of the skinplate, on the upstream side. The wire rope/chain then contacts the skinplate over a portion of the gate height and eventually separates tangentially to the skinplate arc. This arrangement affords the smallest operating capacity (Figure 2-1). Pivoting hydraulic cylinders are also used to operate radial gates. Two cylinders, one at each end of the gate, attach to the gate arms on the downstream side of the gate leaf. Alternatively, one cylinder may be used at the centerline of the gate leaf, on the downstream side. Figure 2-29 shows a hydraulic cylinder operated radial gate and Figure 2-30 shows a picture of radial gates on a spillway.

2.4.10 Roller dam gate

A roller dam gate is a spillway crest type gate that consists of a horizontally orientated cylindrical shell that is raised or lowered to pass water. The cylindrical shell is internally reinforced with structural ribbing and is supported at either end. The gate rolls up and down on an inclined rack embedded in the side piers. Roller Dam gates are either single apron non-submersible type or double apron submersible type. The non-submersible type passes flow beneath the gate as the cylindrical shell is rolled up the track by a chain drive system. The submersible type passes flow over the gate as it is lowered into a recess in the ogee crest by a chain drive system. The sides of the cylindrical shell are equipped with end shields with rubber or wood seals attached that seal against plates embedded in the side piers. A bottom seal is attached to an apron extension of the cylindrical shell and seals against the spillway ogee. Figure 2-31 shows a non-submersible gate, which is the most common design of the roller dam gate. Figure 2-32 and Figure 2-33 show pictures of two non-submersible roller gates.

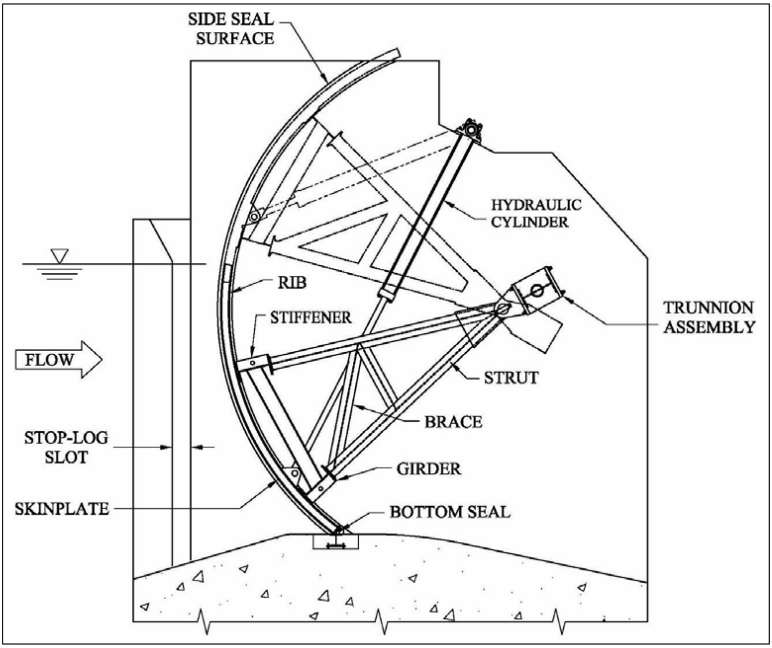


Figure 2-29. Hydraulically operated radial gate.

Figure 2-30. Radial gates.

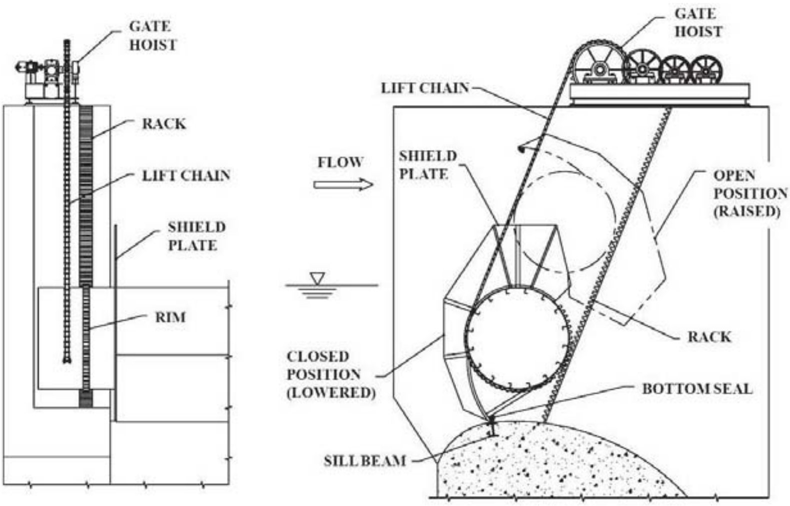


Figure 2-31. Roller dam gates: Single apron nonsubmersible gate.

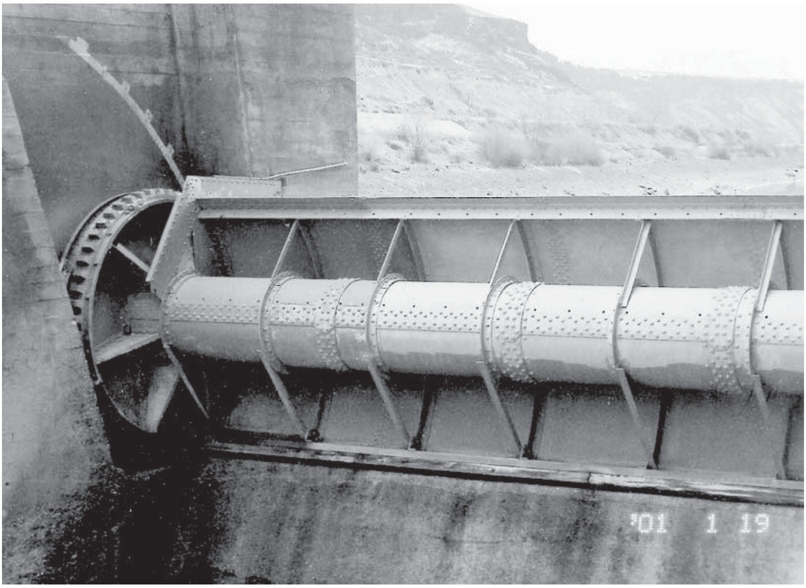


Figure 2-32. Non-submersible roller dam gate (Courtesy of USBR).

Figure 2-33. Roller dam gate (Courtesy of USACE).

2.4.11 Wheel and roller mounted gates

Wheel and roller mounted gates are defined here as vertical (or near vertical) lift gates with a wheel or roller type support system that transfers the hydraulic load from the gate to the sides of the water passage. The wheels or rollers minimize friction forces when moving the gate, thereby keeping the operating mechanism capacity as low as possible. These gates can be used in a wide range of head for spillway or intake/outlet gates. Wheel or roller mounted gates can generally be operated under full or partial differential head and are used for emergency closure, maintenance, flood control, and sometimes flow regulation.

This type of gate consists of a flat structural steel gate leaf with wheels/rollers at each end. The gate leaf is composed of a skinplate supported by main horizontal girders and secondary stiffening members. The horizontal girders frame into endplate assemblies on each side of the gate that support the wheels/rollers. Deep slots are provided in the sidewalls of the water passage on which the wheels/rollers are supported. Depending on the design application, a roller gate is either upstream sealing or downstream sealing. Upstream sealing gates have the skinplate on the upstream side with the supporting members on the downstream side. The seals, usually rubber, are mounted on the skinplate and seal against the upstream side of the gate slot. Downstream sealing gates have the skinplate on the downstream side and the structural framing members on the upstream side. The seals are mounted to the downstream side of the skinplate and seal against the downstream side of the slot. Upstream sealing gates permit dewatering of the gate slot and are used when the gate is located in a tunnel. Access for inspection of the tunnel and gate is gained via the slot. Upstream gates are also used in heavy silt and debris environments where the framing members and wheels need to be protected. The bottom seal, usually a bar type seal, is clamped to the bottom of the skinplate and seals against a steel beam embedded flush in the floor of the conduit.

These gates can be designed in a single section or multiple sections depending on the capacity limitation of the handling equipment or the overhead clearance. The sections of a multiple section gate seal against one another using a rubber gasket.

Several types of operating machinery are used for these types of gates including both dedicated and traveling machinery. The gates are typically self-closing under flow therefore wire rope hoists can be used. Hydraulic cylinders are commonly used with or without connecting rods depending on the location of the hydraulic cylinder with respect to the gate. Vertical lift spillway gates usually use wire rope hoists mounted on support structures that extend up as high as the gates open position.

Two major types of wheel-mounted gates are commonly used: the fixed wheel and coaster gate. These two types of gates use different wheel/roller arrangements as described below. Other wheel mounted gate designs have been based on modified configurations of the two basic arrangements. These less common gate types are also discussed below.

2.4.11.1 Wheel-mounted gate

Wheel-mounted gates have a series of independent wheels mounted along the height of the gate on each side. The wheels carry the water thrust load to vertical steel tracks embedded in the concrete on the downstream side of the gate slots. The wheels provide low-rolling friction coefficients (versus sliding friction) for raising and lowering the gate under full head and flow conditions. The wheels are usually equipped with either roller bearings, bronze bushings, or self-lubricating bushings to reduce wheel-to-axle friction (Figures 2-34 and 2-35).

2.4.11.2 Roller-mounted gate

A roller mounted gate (Figures 2-36 and 2-37) is more often used in high head applications and uses two continuous roller trains, one on each side of the gate. The roller train consists of a series of stainless steel rollers linked together with pins and sidebars (Figure 2-37). The rollers have a smaller diameter and are spaced close together than wheels for a comparably sized gate, affording several more points of contact to transfer the hydraulic load to the support tracks in the gate slots. The roller trains are confined in fixed carriages at either side of the gate. The roller train tracks within this carriage as the gate moves. Where the sealing surface is vertical, roller-mounted gates are commonly referred to as coaster gates. If the sealing surface is sloped, the roller-mounted gates are typically referred to as caterpillar or broome gates.

2.4.11.3 Paradox gate

The paradox gate (Figure 2-38) is similar to the ring follower gate (p 62) except that when the leaf of a paradox gate is in any position other than full

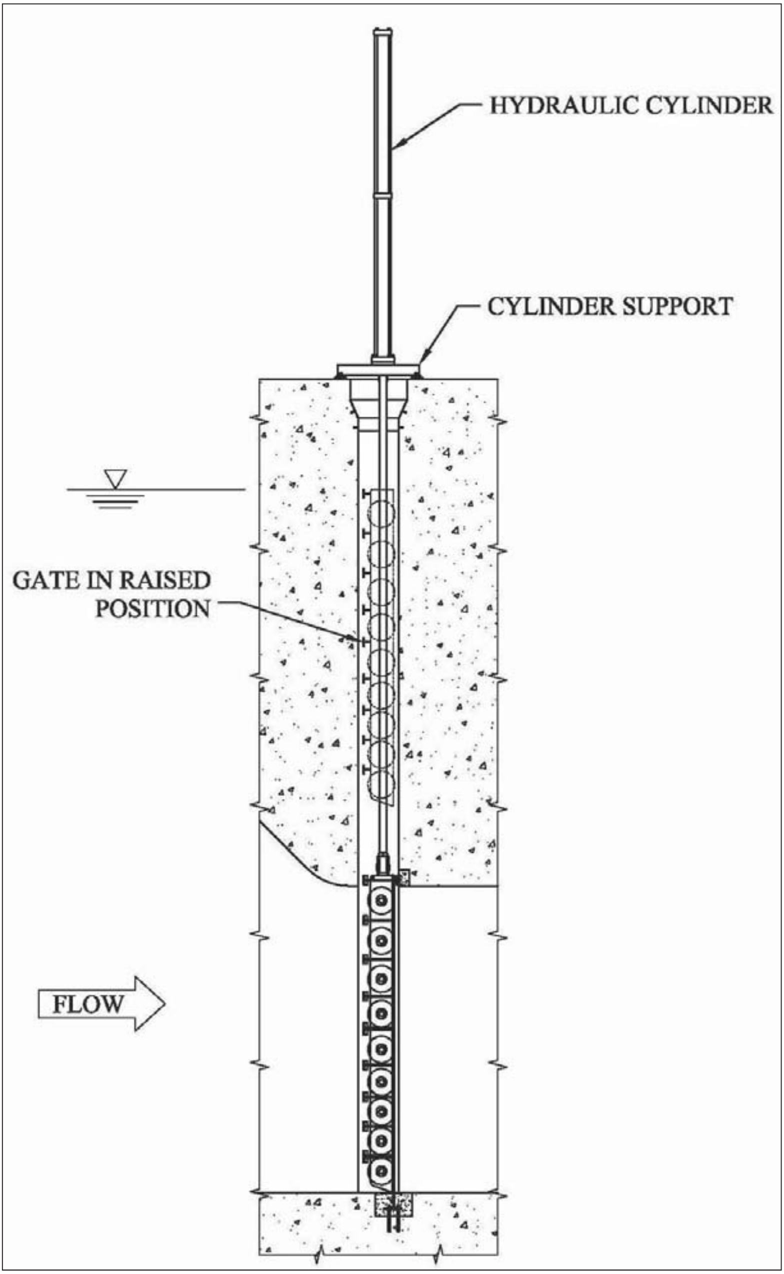


Figure 2-34. Wheel-mounted gate.

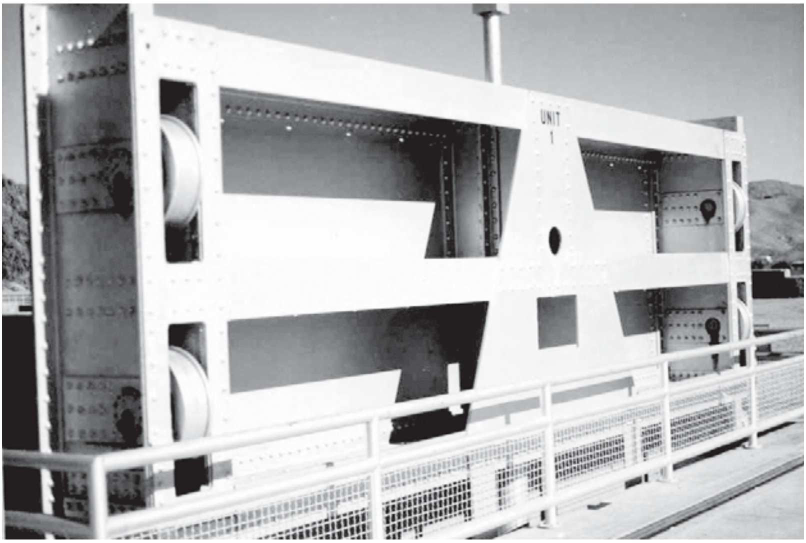


Figure 2-35. Wheel-mounted gate (Courtesy of USBR).

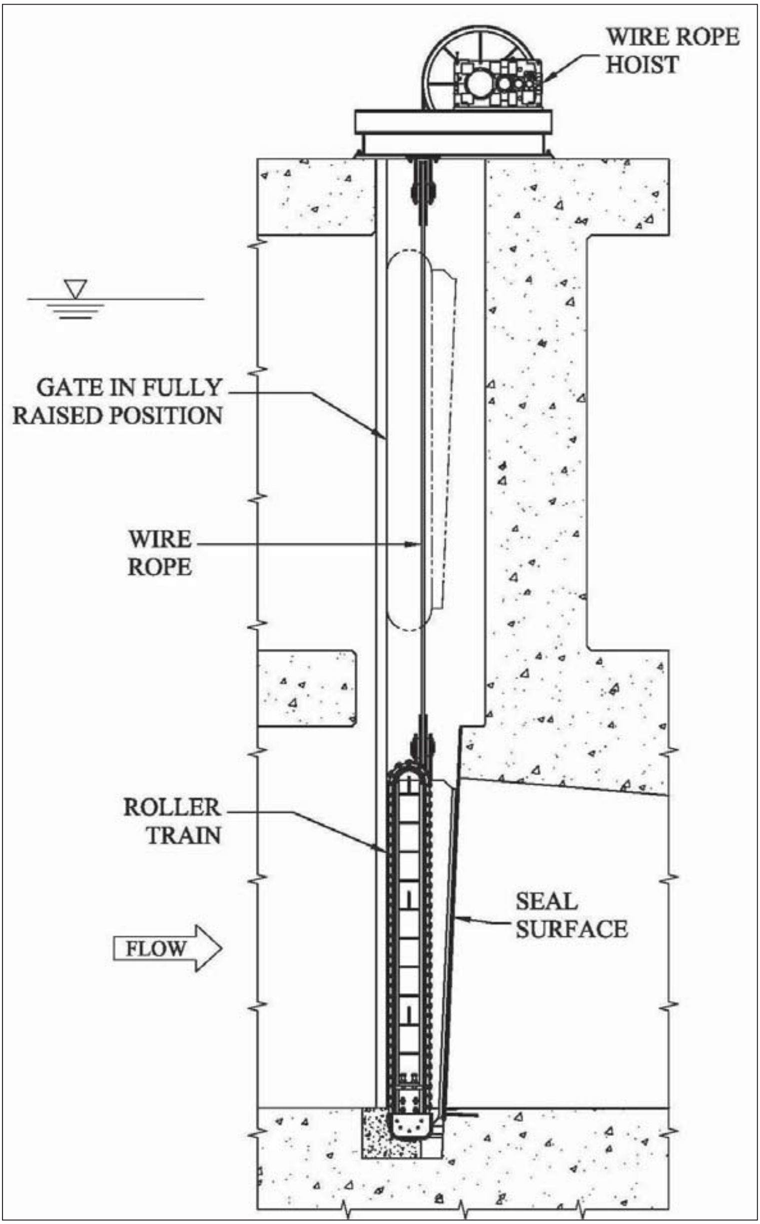


Figure 2-36. Caterpillar gate.

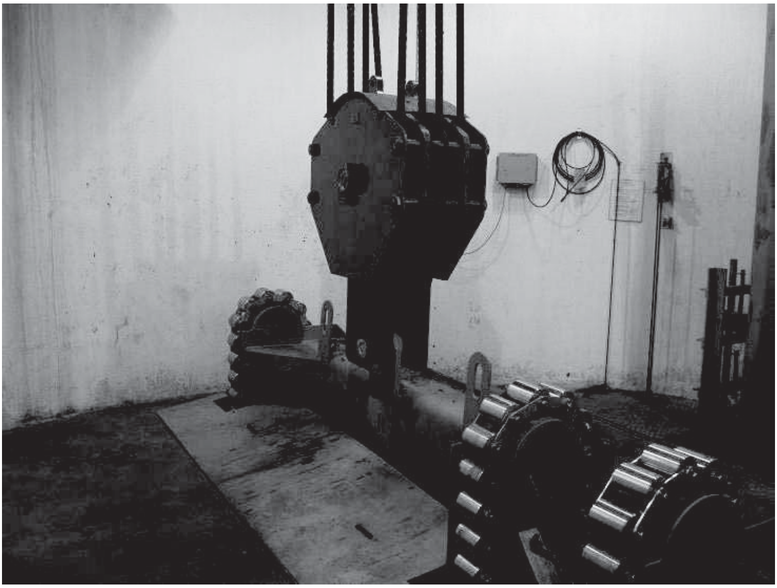


Figure 2-37. Caterpillar gate.

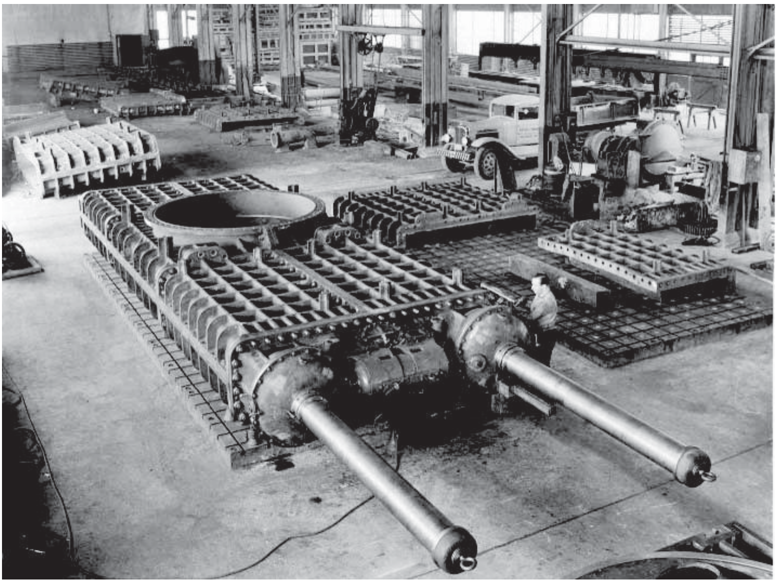


Figure 2-38. Paradox gate (Courtesy of USBR).

closed, continuous roller chains support hydraulic loads on the leaf. The name Paradox comes from the fact that the gate leaf is first moved upstream before being raised from the fully closed position. This action unseats the seal bars to eliminate sliding friction from gate operating forces. Before lifting the leaf, the hoist first raises a roller wedge system against tapered tracks, pushing the gate leaf upstream. Then the roller carrier linkage engages and lifts the unseated gate leaf. Roller chains on either side of the gate leaf (independent from the roller wedge system and tapered tracks) roll on tracks on the downstream side of the gate and bonnet bodies. During closure of the gate, stops restrict the leaf movement downward, but the roller wedge carriers to continue to descend. Withdrawal of the roller wedge system allows the leaf to move downstream to seat the leaf seal bar against the body-mounted seal ring. As with the ring seal gate, the hoist capacity is significantly reduced when compared to the ring follower gate. When these gates were developed, mechanical hoists were commonly used for operation prior to the development of hydraulic hoists.

2.4.11.4 Ring seal gate

A ring seal gate is basically a wheeled version of a ring-follower slide gate. They look almost identical to paradox gates but the sealing surface is upstream instead of downstream. Ring seal gates are used in circular conduits as emergency/guard gates for a downstream regulating valve. Unlike a ring follower slide gate, continuous roller trains or anti-friction wheels are provided on the leaf and follower, which significantly reduce friction during operation of the gate. The name, however, is derived from the unique means by which the gate seals. A floating seal ring is mounted to the upstream side of the gate body. The seal ring, made of bronze (sometimes with a rubber insert), is pressurized by external means when the gate is in the full open or closed position and forced against a fixed stainless steel seal ring on the gate or follower. When the gate is to be operated, pressure is released and the seal ring retracts to reduce sliding friction and prevent damage. The primary purpose of these two features is to reduce the friction and hoist capacity from that required for sliding-type ring-follower gates. The hoisting force required was of considerable concern when these gates were invented in the 1930s. At that time, mechanical rather than hydraulic hoists were used for gate operation. Ring seal gates have not been constructed for a long time and therefore are very uncommon.

2.4.11.5 Stoney gate

Stoney gates (Figure 2-39) resemble coaster gates except that the rollers are in a line instead of a continuous chain. The two lines of rollers are independent of the gate leaf and the tracks. The roller line moves freely between the fixed guide tracks of the embedded support frame and the gate leaf. The roller lines translate up and down at half the distance the gate leaf moves as the gate is opened and closed while transferring the hydraulic load from the gate leaf to the tracks. Stoney gates have not been constructed for a long time and therefore are uncommon.

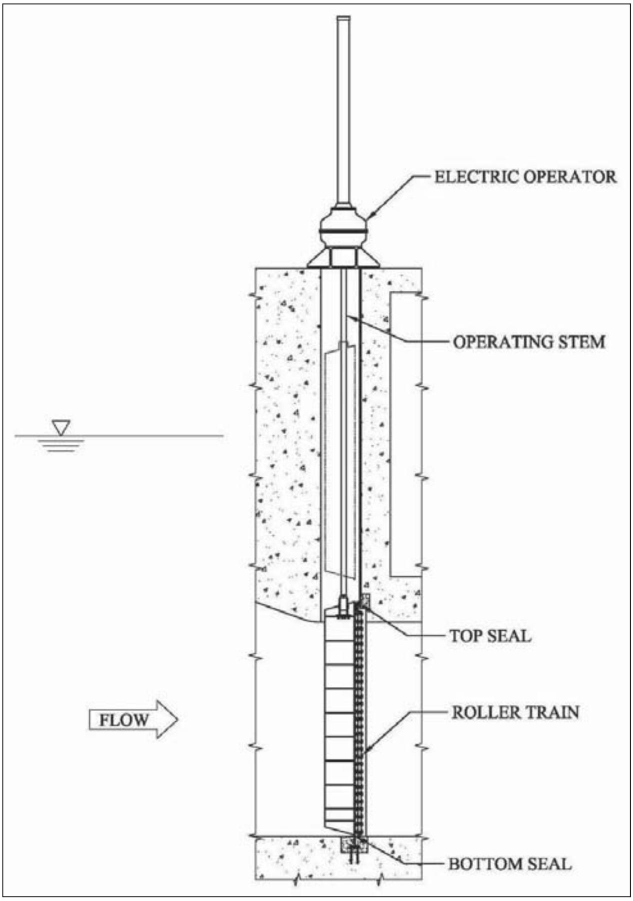


Figure 2-39. Stoney gate.

2.4.12 Vertical lift slide gate

"Slide gate" is a general term used to describe a gate that normally consists of a flat gate leaf that is commonly operated under either differential or balanced head pressure conditions and slides against bearing surfaces during operation as opposed to rolling on wheels as in wheel-mounted type gates. Slide gates are used in numerous low head and high head applications for flow regulation and emergency closure. Slide gates allow maintenance or inspection of downstream regulating valves and conduit. Cracking open allows filling of the downstream conduit. Slide gates are the simplest form of gate and are very common. Size and head limitations are governed only by the capacity of the mechanism needed to operate the gate.

Slide gates are designed for installation on the upstream face of a dam structure, in a vertical shaft within a pipe or conduit, in a gate chamber, etc. A gate leaf, supported on the sides within the gate slots (and sometimes at top and bottom) is typically operated in a vertical plane. The gate leaf consists of a skinplate supported by horizontal girders and secondary stiffeners. The skinplate can be provided either on the upstream or downstream side of the leaf, but typically is on the downstream side. The girders frame into sideplates that are equipped with support bars on the downstream side, which slide against embedded metal surfaces with considerable friction. In addition to the gate weight, the operating equipment must overcome the sliding friction force. Low friction bearing materials, such as bronze, fluorocarbon or Ultra High Molecular Weight (UHMW) Polymer are often used as the sliding surface to minimize friction forces.

The sealing system for slide gates may be an independent flexible rubber sealing system or a rigid bar sealing system that also acts as the bearing/sliding surfaces. When used, rigid seal bars are typically metal on metal (usually bronze on stainless steel) or fluorocarbon on stainless steel.

Slide gates may be operated with a system capable of pushing the gate leaf down as well as pulling up, therefore wire rope and chain hoists are not used. Hydraulic cylinders or screw stems are used exclusively for this type of gate.

2.4.13 Bonneted slide gate

The bonneted slide gate (Figures 2-40 and 2-41) is a slide gate that is self-contained within a pressurized enclosure and does not require a gate slot and

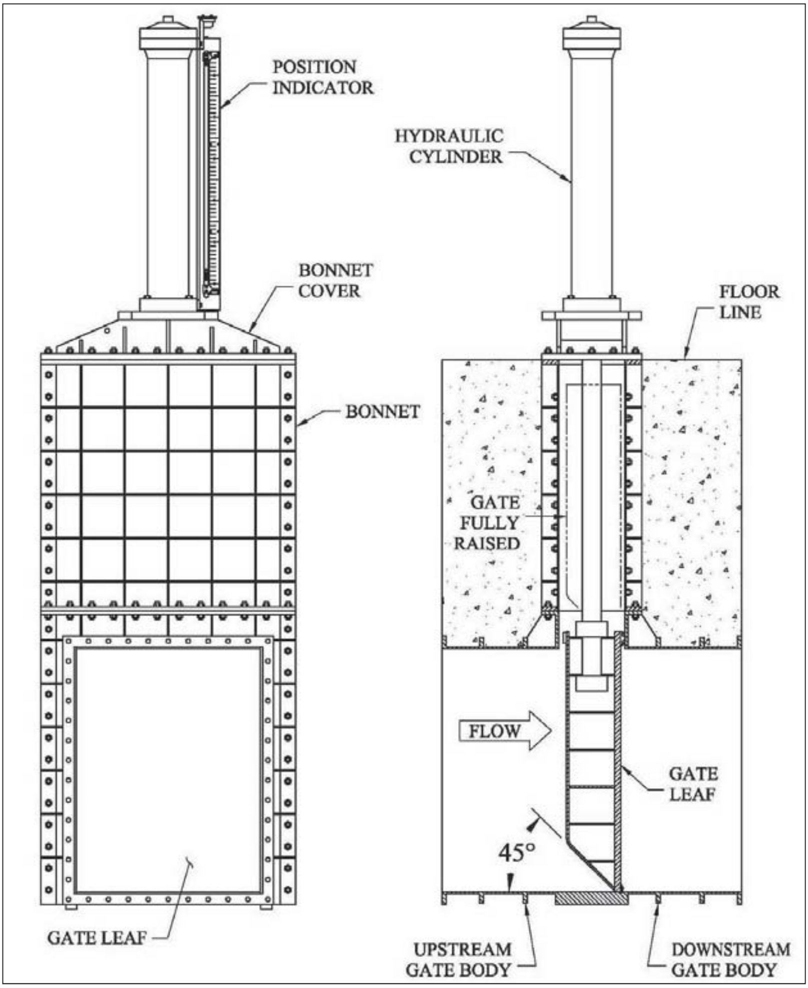


Figure 2-40. Bonneted gate.

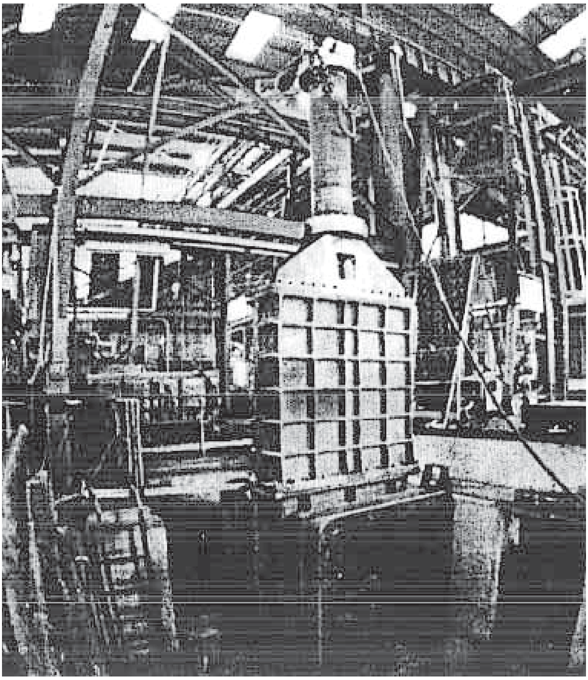


Figure 2-41. High pressure bonneted gate
(Courtesy of USBR).

shaft that extends up to the free surface water level. The bonneted gate contains upper bonnet bodies and a cover that completely encloses the gate leaf in a cast iron or welded steel body. The operating hoist system is mounted on top of the bonneted cover. Bonneted gates are commonly used in low level outlets where it is not practical or possible to have a slot and shaft that extends to the free surface water level. Bonneted gates are often placed back to back in a steel lined conduit that extends upstream of the upstream gate and downstream of the downstream gate. The downstream gate is used as the flow regulating gate and the upstream gate is used as the guard/maintenance gate.

The self–contained pressurized gate enclosure consists of upstream and downstream gate bodies with seal bars and vertical slots for support of a gate leaf, a steel bonnet that houses the leaf when in the open position, and a cover that is attached to the top of the bonnet and encloses the bonnet while supporting the base of the hydraulic cylinder or screw stem. The gate bodies and bonnet are embedded in concrete. The bonnet cover is removable for maintenance. The operating mechanism is mounted on the bonnet cover and the operating stem extends through the bonnet cover to the gate leaf. The gate bodies, bonnet, and bonnet cover are heavily ribbed to prevent distortion during embedment in concrete and to withstand the internal pressure where not embedded (as in the case of the bonnet cover).

The mating seats on the gate leaf and in the gate bodies and bonnet serve as sliding surfaces and sealing surfaces. Bonneted slide gates are normally not equipped with rubber seals because of difficulty accessing them for maintenance and replacement.

Cast steel and cast iron were commonly used for bonneted gate leaves in the past. However, more recent designs often use structural steel weldments because of economy and material quality. Air-inlet manifolds are usually provided on the downstream side of the downstream gate body when bonneted gates are located at some distance upstream from the outlet end of the conduit.

2.4.14 Jet-flow gate

The jet-flow gate (Figures 2-42 and 2-43) was developed in the mid-1940s by the U.S. Bureau of Reclamation. Jet-flow gates are used as regulating gates under free or submerged discharge conditions and have proved to have excellent flow characteristics while nearly eliminating cavitation and vibration problems. Historically there have been two basic designs: the older mechanical operated type, and the more recent hydraulically operated type. Jet-flow gates are a form of bonneted slide gate with the major difference being in the design of the gate body structure. The gate body incorporates a circular orifice in the form of a truncated conical nozzle somewhat smaller in area than the incoming conduit. A floating seal ring forms a circular discharge orifice at the downstream end of the nozzle. The gate leaf that contacts the seal-ring and is moved across the seal-ring orifice to regulate flow discharge. A contracted, jet-type discharge springs free of gate leaf slots in the gate body. The contracted jet is responsible for the name of the gate and eliminates cavitation otherwise caused by the gate slot discontinuity.

The gate leaf and body are typically made of structural steel, except that the upstream face of the gate leaf, which is in sliding contact with the seal ring, is made of corrosion resistant stainless steel. The seal ring is made of bronze. The gate leaf is typically opened/closed by means of a hydraulic cylinder.

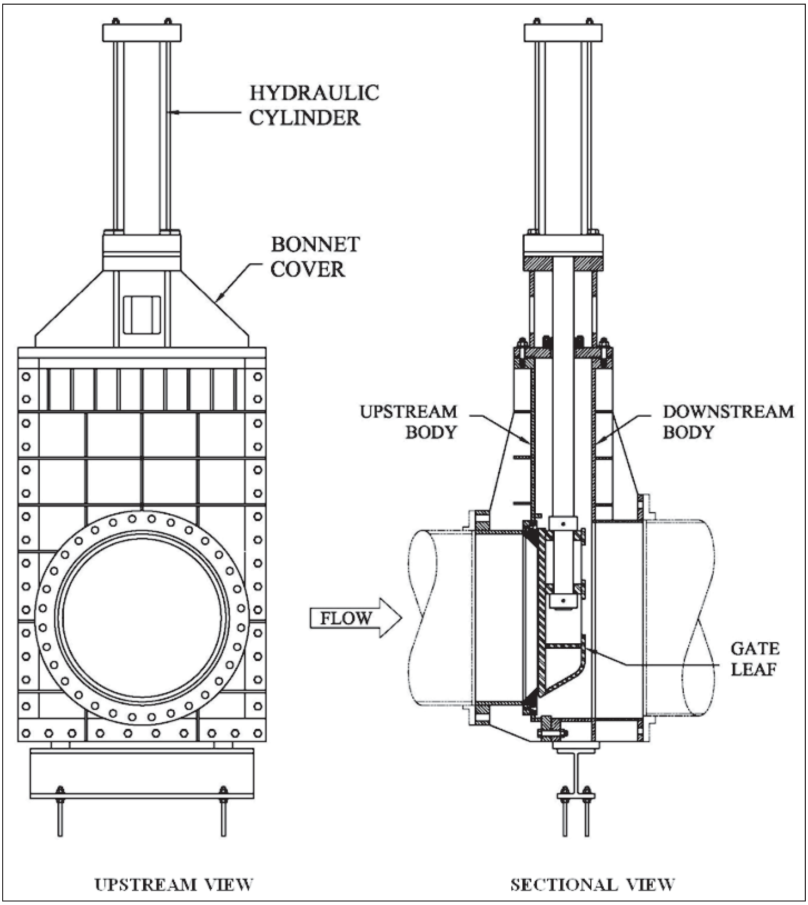


Figure 2-42. Jet-flow gate diagram view.

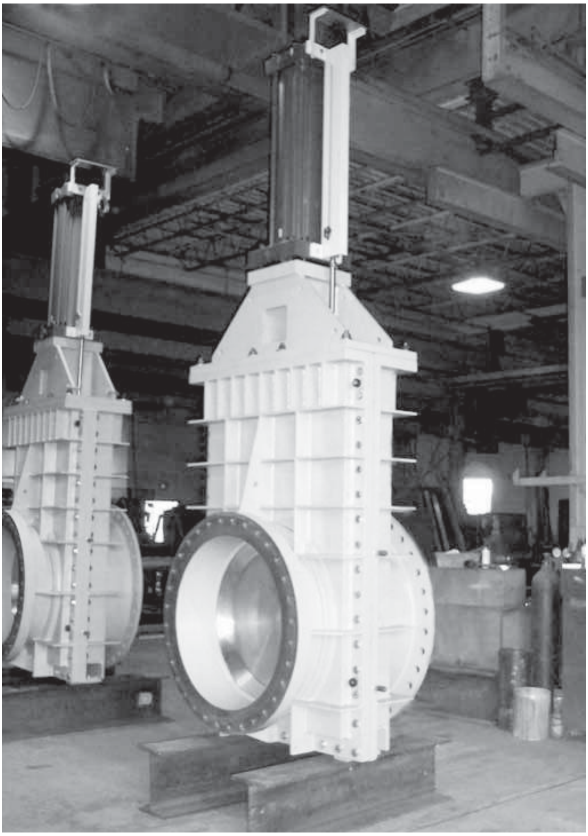


Figure 2-43. Jet-flow gates.

2.4.15 Ring-follower gate

Ring-follower gates (Figures 2-44 and 2-45) are slide gates used exclusively in circular conduits as guard/emergency gates. Ring-follower gates are not used for regulation of flow. A ring-follower gate is a modification to the bonneted slide gate used exclusively in rectangular transitions. The gate consists of a flat leaf, double the height of the conduit diameter. The top half of the leaf is composed of a bulkhead portion that blocks the conduit when the gate is closed, and the bottom half (termed "the follower") is a reinforced ring that has an inner diameter equivalent to the conduit diameter. The follower aligns concentrically with the conduit when thegate is open, thereby creating an unobstructed continuous fluidway. An upper and lower bonnet is provided to

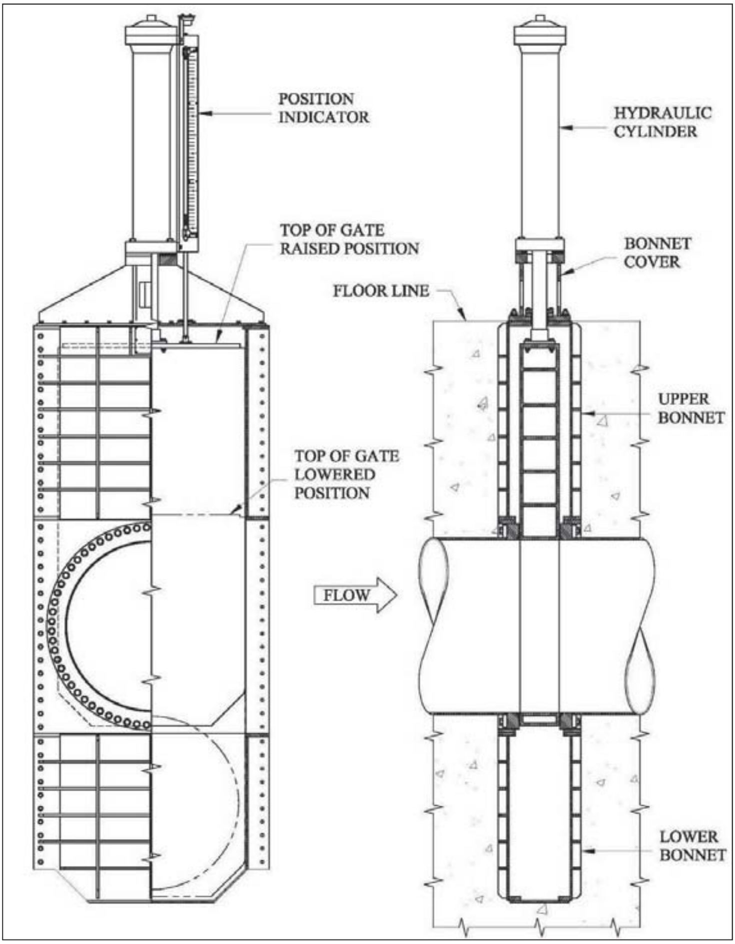


Figure 2-44. Ring-follower gate.

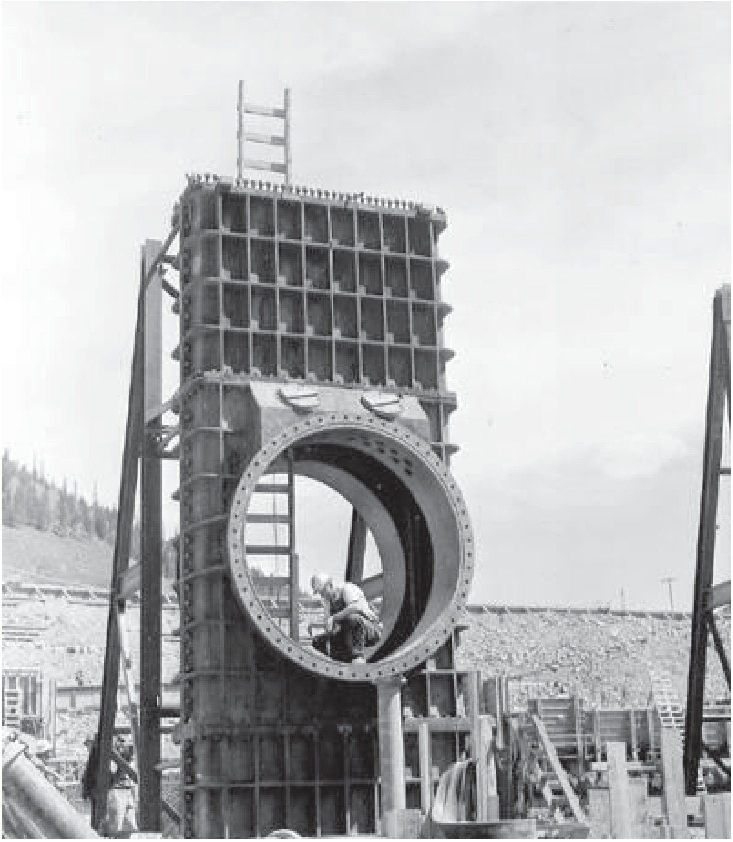


Figure 2-45. Ring-follower gate body before installation.

receive the portion of the leaf not in the flow path. The full height of the gate assembly is therefore approximately 3 to 3.5 times the diameter of the opening. As with the bonneted slide gate, the bonnets and gate bodies are fully embedded in concrete. The bonnet cover supports the hydraulic cylinder.

The seating of the gate leaf is accomplished with metal-to-metal seats, similar to a typical bonneted slide gate. The gate-leaf seats both in the full open and full closed positions and acts to transfer the hydraulic load from the leaf to the gate body while also acting as the sealing mechanism. Gate mounted bronze seats and body mounted stainless steel faces are generally used.

2.4.16 Sluice gate

A very common type of slide gate is called a “sluice gate” (Figures 2-46 and 2-47). Sluice gates are mounted to the upstream or downstream face of a wall and use a system of wedges for seating when the leaf is in the closed position. Several types of gates can be referred to as “sluice gates” because the term is a functional reference. The term “sluice gate” is a commonly accepted term for a cast iron, bronze seated gate of standard manufactured slide gate available in standard sizes and head ranges. This type of sluice gate will be described herein. Sluice gates are used in low head applications and can be designed for regulation of sluicing flows.

A cast iron thimble with either a circular or rectangular opening is normally embedded in the support wall of the central structure as a means of attaching the gate to the wall and to provide the proper opening cross section. The sluice gate assembly is mounted to the thimble. The gate assembly consists of a frame, wedge system, and a seal system.

The wedging system serves to seat the gate on three or four sides of the disc. The gate frame is a cast iron structure that supports the gate disc and transfers the hydraulic loads to the wall thimble. The gate frame includes guides and half of the wedging system. The gate disc is a casting consisting of a faceplate and integral stiffening ribs, and contains the other half of the wedging system. The gate is either mounted on the upstream side or downstream side of the support wall.

The gate is operated in a vertical plane by the operating mechanism. As the gate is closed, the wedging system forces the disc against the frame to seat the gate. The seating system consists of bronze seating surface on the gate disc and either bronze or stainless steel seating surface on the gate frame.

Sluice gates are operated using either a screw stem hoisting system or hydraulic cylinder system. Figure 2-46 shows a hydraulic cylinder system with stem connections. The screw stem hoist or hydraulic cylinder is usually mounted in a dry compartment or on the deck surface of the control structure. The operating device connects to the gate disc through a series of intermediate stem extensions coupled together. The gate stem connects to the gate disc via a thrust nut. Intermediate stem extensions are supported against lateral movement by stem guides set at defined intervals on the wall of the control structure to prevent stem buckling of the rods during closure of the gate.

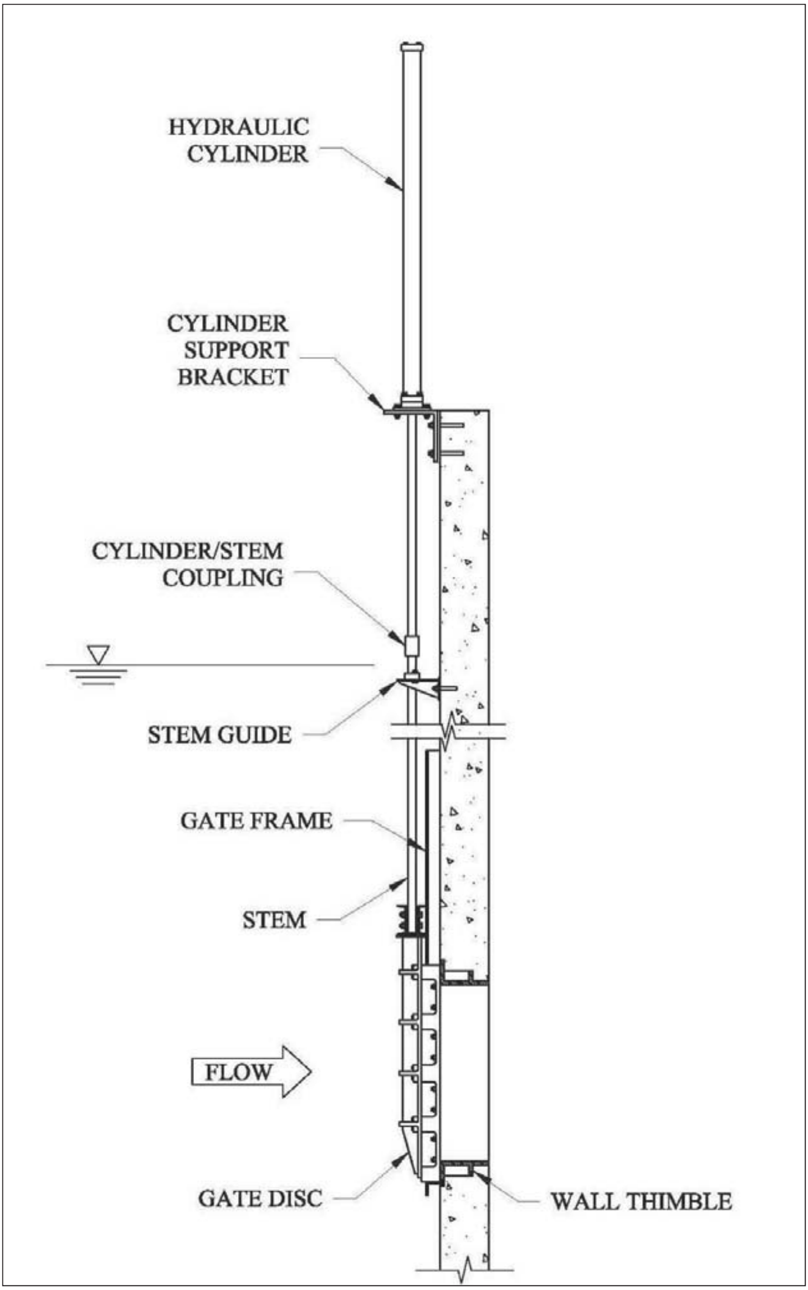


Figure 2-46. Sluice gate.

Figure 2-47. Sluice gate outlet work
(Courtesy of USBR).

2.4.17 Bear-trap gate

A bear-trap gate (Figures 2-48 and 2-49) is a type of hinged crest gate that operates using buoyancy, similar to the drum gate previously described. A bear-trap gate consists of two leaves, an upstream leaf hinged and sealed along its upstream edge, and a downstream leaf hinged and sealed along its downstream edge. When the gate is fully lowered, the upstream leaf lies on top of the downstream leaf in the horizontal position within a gate chamber just below the crest of the spillway. The two leaves have a sliding seal or hinge at their juncture and are sealed against the piers at each side. Fill lines and valves allow filling of the gate chamber from the headwater. The water entering the chamber forces the buoyant gate leaves to rise so long as the two leaves remain in contact. The amount of water in the chamber controls the level of the gate.

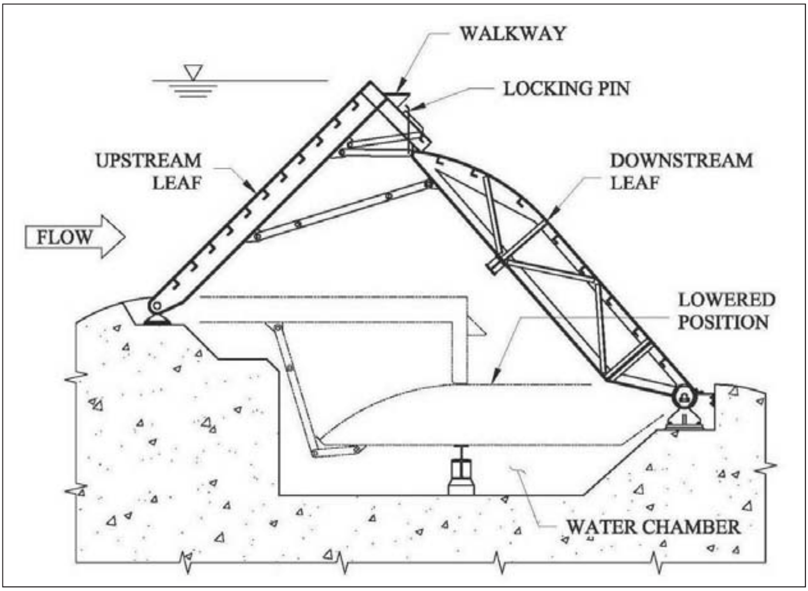


Figure 2-48. Bear-trap gate.

Figure 2-49. Bear-trap gates.

Bear-trap gates were used extensively in the past as regulating gates in movable navigation dams and for log-sluicing operations. An improved form of the bear-trap gate was developed and widely used in central Europe as an automatic spillway crest. However, these gates require regular maintenance, have a history of operational problems, and have not been installed for the past several years.

2.4.18 Clamshell gate

A clamshell gate (Figures 2-50, 2-51, and 2-52) is designed for use as a flow-regulating device either under free or submerged discharge. The body of the gate is a cylindrical steel section with a single radius machined from the centerline to the top and bottom of the cylindrical section on the downstream end. The operating elements consist of two radial segments that meet and seal along the transverse centerline of the body. These segments rotate about trunnion pins fixed to the outer wall of the gate body. Moving the two radial segments away from each other opens the gate (Figure 2-50). The seal for the gate is mounted to the body. The radial segments slide over the seals as they open and close.

The operating mechanism, usually two hydraulic cylinders, slide the two gate leaves open and close. A linkage mechanism assists in the operation of the gate.

2.4.19 Cylinder gate

Cylinder gates (Figure 2-53) provide a relatively simple and effective installation for vertical intakes. They are gravity closure gates used primarily for emergency closure of conduit and penstock intakes and sometimes for regulating discharges.

A cylinder gate is composed of a cylindrical shell that is raised and lowered to control flow through radial openings in the intake structure (Figure 2-53). Cylinder gates may be located on the inside or the outside of a circular intake structure, but an inside location is more common for maintenance reasons (Figure 2-54). Seals at the top and bottom of the cylinder make contact with mating seats when the gate is closed. Up to three equally spaced hydraulic or screw stem hoists have been used for gate operation. Hydraulic cylinders have also been used.

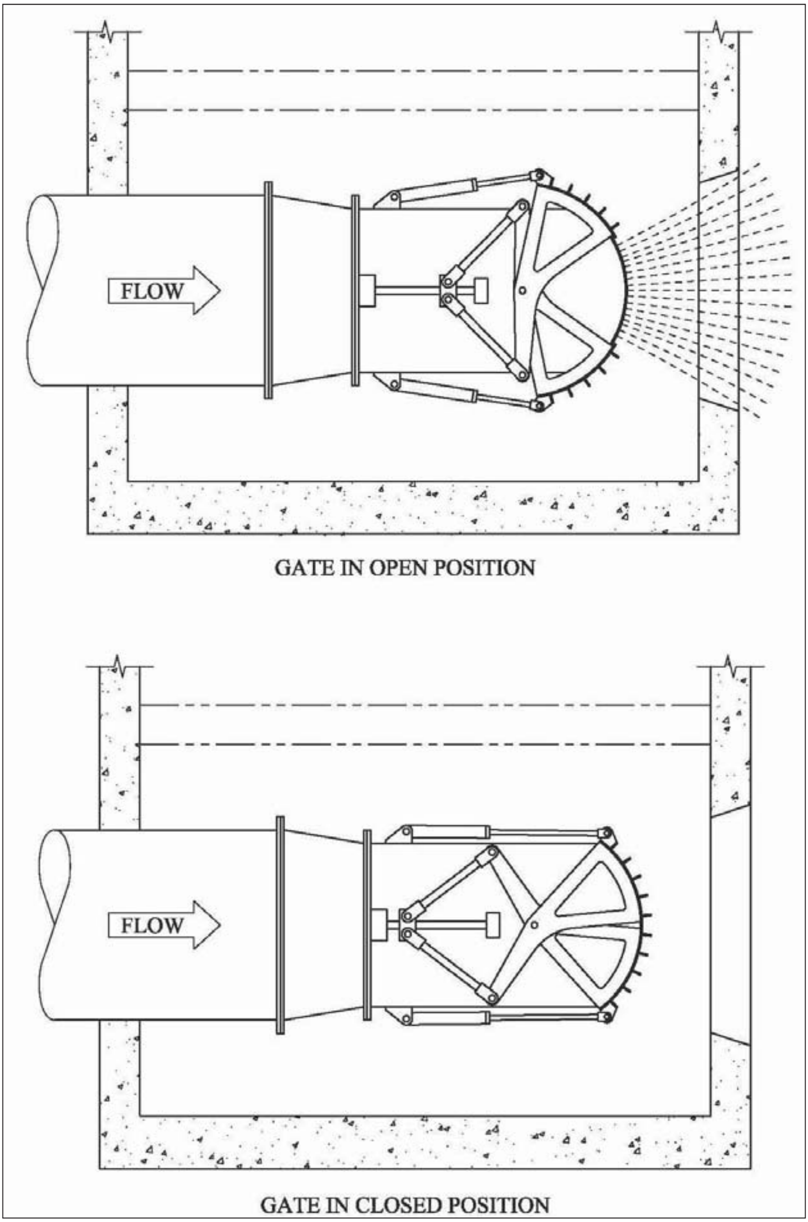


Figure 2-50. Clamshell gate.

Figure 2-51. Clamshell gate before installation (Courtesy of USBR).

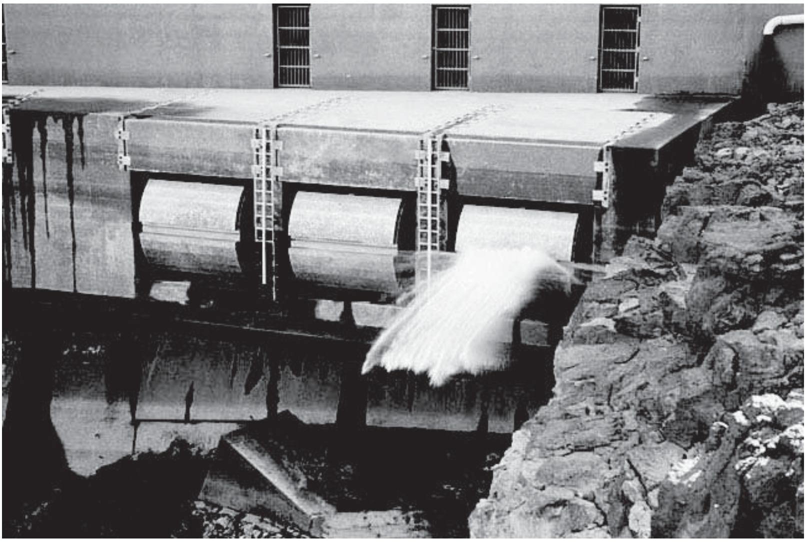


Figure 2-52. Clamshell gate after installation (Courtesy of USBR).

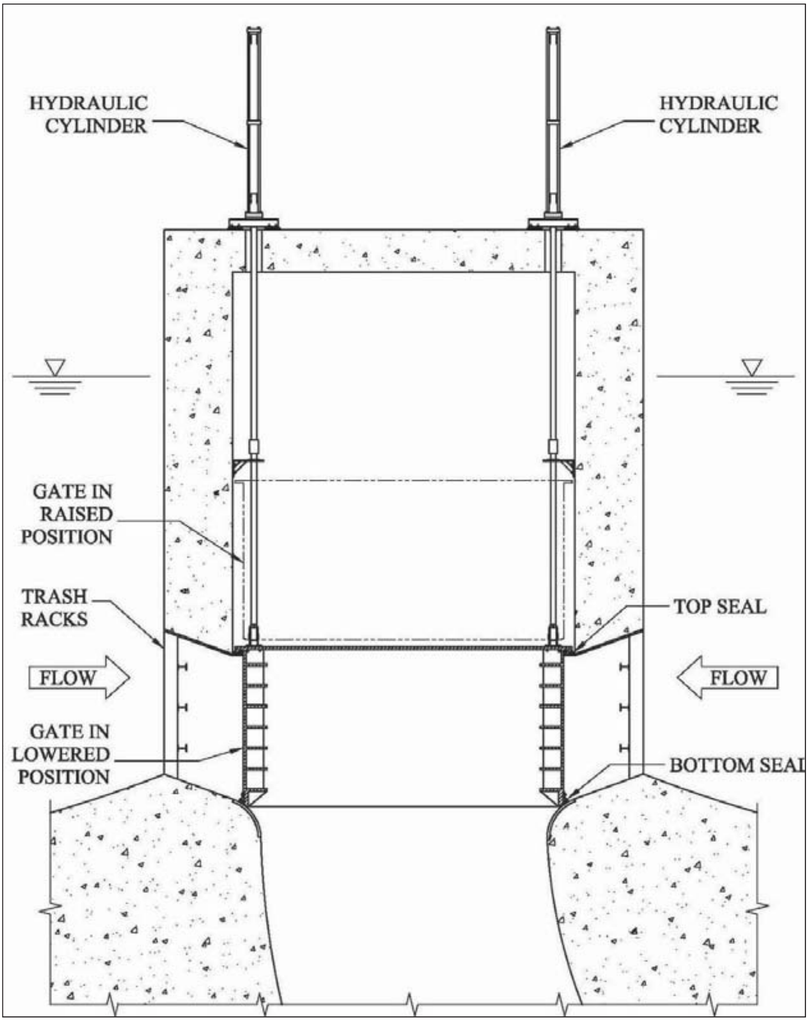


Figure 2-53. Cylinder gate.

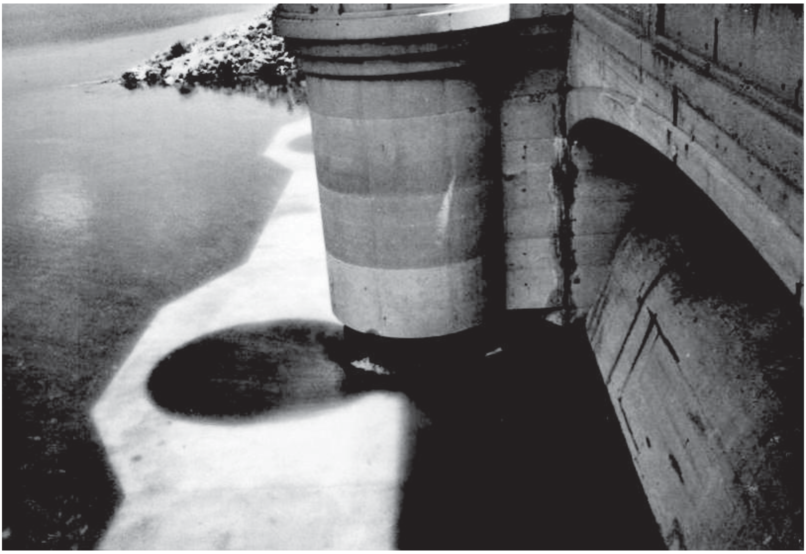


Figure 2-54. Intake with operating cylinder gate (Courtesy of USBR).

2.4.20 Ring gate

A ring gate is a buoyant type gate used to regulate flow through a “morning glory” type spillway. The gate is a ring-shaped vessel (Figure 2-55) that floats up and down in a gate chamber surrounding the morning-glory spillway crest. When the gate is lowered to its full open position, the top surface of the gate and the concrete form the bellmouth shaped spillway entrance. The gate is raised vertically by admitting water to the gate chamber and the level of water is controlled by a drain valve.

2.4.21 Fuse gate

A fuse gate (Figure 2-56) is the mechanical equivalent of a fuse plug. This type of gate was developed in France in 1989. A fuse gate uses gravity, water, and stability for its operation, and consists of these main components:

1. Bucket shape steel structure normally flooded to the upstream water level
2. An intake well that accepts water above a predetermined level
3. A concrete base structure with a pocket on the underside to accept water from the intake well
4. Bottom and side seals
5. Downstream support or pivot block.

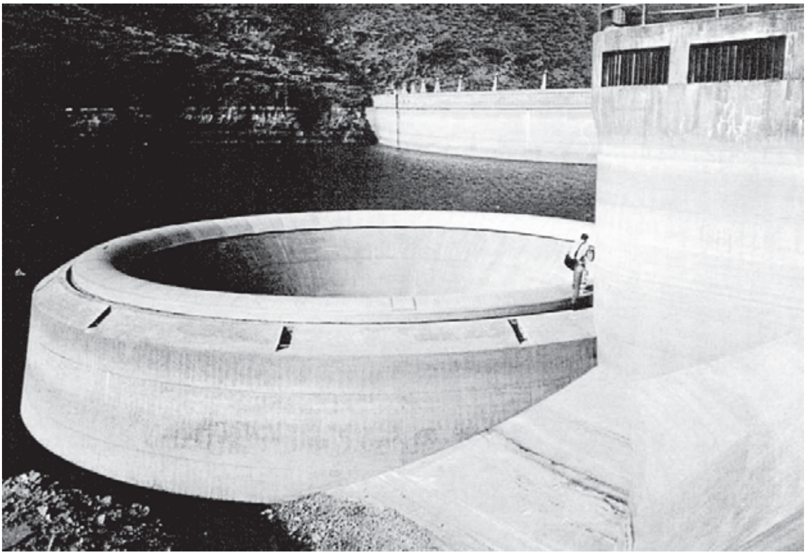


Figure 2-55. Ring gate (Courtesy of USBR).

For the normal range of reservoir levels, the water fills the bucket and overflows over the gates as it would over a weir (Figure 2-57). When the water level rises to a predetermined level, the gates are designed to release to pass much greater flows. The fuse gate releases, not by mechanical means, but rather due to designed instability. This is accomplished using water pressure. With the bucket full, the fuse gate is stable. After the upstream water level increases to a predetermined elevation, water begins to spill into the intake well. The intake well is connected to the pocket in the underside of the base. When the intake well becomes flooded, the water pressure exerts uplift on the fuse plug base, which decreases its rotational stability. Eventually the gate tips about its downstream edge.

2.5 Gate sealing systems

2.5.1 General

To effectively minimize leakage downstream of a water control gate, special sealing systems are used between the gate and the perimeter of the water passage. The diversity in the types of sealing systems is large and depends on the arrangement and design parameters of the installation.

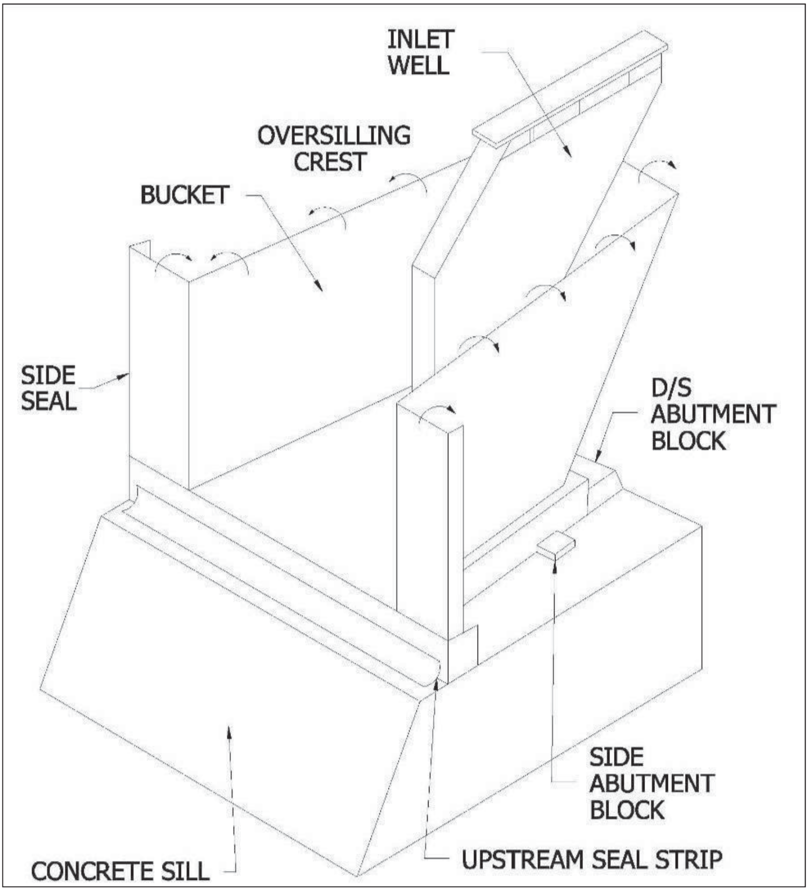


Figure 2-56. Fuse gate.

Figure 2-57. Labyrinth fuse gate (Courtesy of USBR).

The sealing system of a water control gate includes two components, the seal assembly (normally gate mounted) and the sealing surface (usually embedded in the concrete perimeter of the water passage). Seals can be of rubber, metal, timber, or a composite material. Sealing surfaces (or seating surfaces) can be metal, concrete, or the (material composition of the) seal assembly of an adjacent gate. Successful sealing depends on both components, seal flexibility and sealing pressure.

The following section will discuss the various types of sealing systems commonly provided on water control gates including flexible sealing systems (usually rubber) and rigid sealing systems that include metal-to-metal seals or fluorocarbon to metal seals.

2.5.2 Flexible sealing systems

The most common type of flexible sealing system consists of rubber seals. In the past, canvas was also used, but it is unlikely that these would still be in service. Most gates are provided with rubber-to-metal sealing systems because rubber provides more flexibility to adjust to irregularities in the sealing surfaces and the metal provides a flat and durable surface on which the rubber will seal. The rubber seal flexibility enables the seal to conform and to compress or deflect against the sealing surface providing a tight seal.

Rubber seals are usually fixed to the gate by means of clamping assemblies, and move with the gate. They normally seal against a smooth, flat, metal sealing frame embedded in concrete. The seal is formed by a compressive force of the seal material to the fixed metal surface either by deflection due to design geometry or hydrostatic head, or both.

The most frequently used sealing surface materials are stainless steel (as stainless plate) or stainless steel clad to carbon steel. Carbon steel and cast iron sealing surfaces have also been used in the past, but are not as commonly used as other materials because of their corrosion potential and because they are extremely difficult to replace.

2.5.3 Common seal types and uses

Standard rubber seal cross sections are supplied by manufacturers throughout the world. Common seal profiles and their common applications with respect to water control gates (Figure 2-58) are:

- *J-type*. This type of seal is commonly referred to as "single stem" or "music note" seal and is one of the most widely used seals because of its flexibility. It is typically used in low to medium head applications on spillway gates, bulkheads, and stoplogs. The seal is clamped at the flat stem end and, which allows the cantilevered bulb to accommodate relatively large deflections without damage. J-seals are commonly used in applications such as side seals on radial spillway gates that expand and contract due to temperature variations. The seal is arranged such that hydrostatic pressure tends to force the bulb against the sealing surface.
- *L-type*. This type of seal is very flexible and is commonly used in low head applications. L-seals can accommodate large deflections that make them useful as side seals for radial spillway gates (for the same reasons as the J-type seals). However, L-type seals may be better than J-type seals on very wide gates where even larger deflections are required.
- *Double-bulb*. This type of seal has two bulbs joined by a common stem, and is often used in low to medium head applications where differential water head can occur on either side of the gate (e.g., in tidal applications), but can also be used in high head applications. The seal is clamped to a

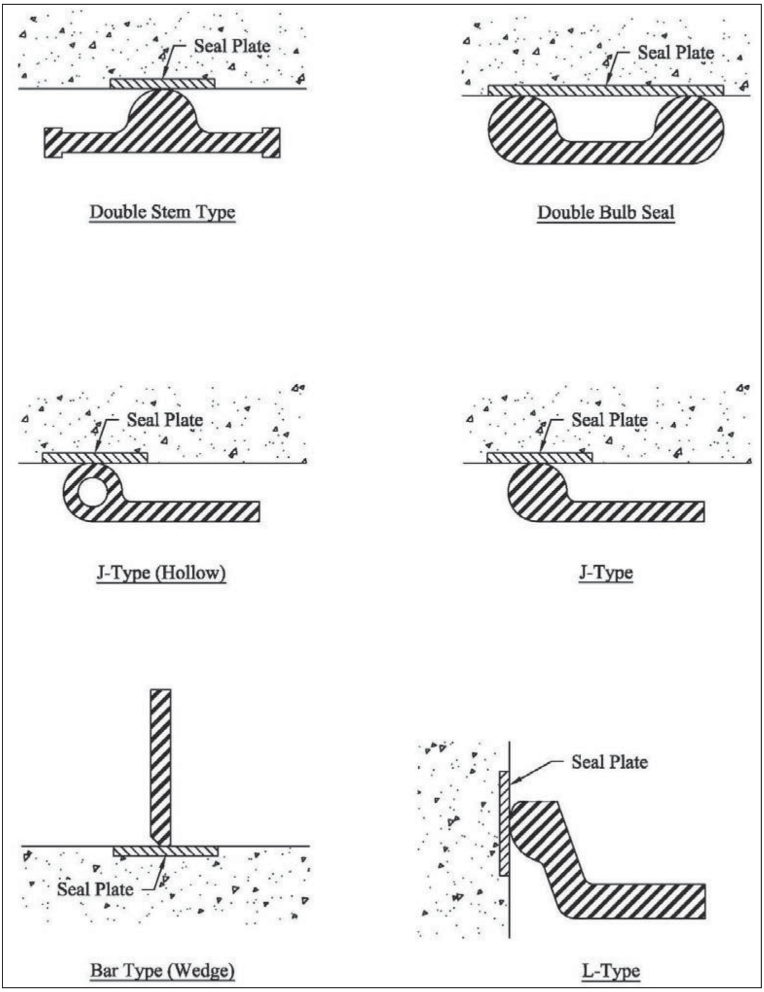


Figure 2-58. Common seal types.

gate by the common stem and effectively acts as two J-type seals placed back to back.

- *Double-stem.* Double-stem seals are also referred to as "center bulb seals." Double-stem seals are securely clamped at both stems of the seal, which provides greater support than J-type seals (which are clamped only at one edge). As a result, double-stem seals can be used in high head applications. The double-stem seal is considered a pressure actuated seal; the seal is typically set for minimal initial deflection and pre-compression and is forced against the sealing surface by differential water pressure applied to the back side of the seal. Double-stem seals are commonly used as lintel seals because they will not tend to roll during operation of the gate like J-type seals. In orifice type radial gates where sealing at the top must be maintained through the opening cycle, double-stem seals are often mounted on the embedded lintel beam and seal against the gate skinplate. Different seal stem configurations and clamping arrangements are used depending on the design head.

- *Bar type*. Bar type seals are typically used as bottom seals on many types of gates. The seal typically extends only a small distance below the bottom of the skinplate and is deformed and/or compressed by that amount by the gate weight. The seal is almost totally confined and supported, therefore vibration is minimized. The bottom seal assembly can be placed on the upstream or downstream side of the skinplate. For gates operated against flow, upstream placement of the seal provides a better spring point for the flow, but results in greater hydrostatic downpull. The bottom of bar type seals are typically chamfered to permit extrusion of the rubber as the seal is compressed to prevent pinching the seal.
- *Inflatable*. Inflatable seals are rubber bladders, pressurized internally by air or water. These seals are typically used in low head applications, but can be used in higher head applications, and are a good option where irregular surfaces are expected or where large gaps must be closed.
- *Strip*. Strip seals are wide, thin, flap or belt type seals. Strip seals are very flexible and capable of conforming to relatively rough surfaces such as concrete. These seals are not commonly used, but when specified, are used only for low head installations.
- *Other seal shapes*. Orifice radial gates are sometimes provided with a square bulb (instead of a round bulb) side seal to maintain better contact with a lintel-mounted top seal for leakage control at the top corners when the gate is in a partially open position. The square seals are typically fully supported at the back instead of cantilevered and are provided with an interference fit against the side sealing surface.

Seal manufacturers have the capability of fabricating seals of almost any shape and size. Custom seal arrangements, different from those described above, may be found on gates worldwide. The seals used above are the most common types and are generally preferred because they can be easily obtained and replaced.

2.5.4 Common seal features

- *Solid vs. hollow construction.* Seals may be provided with solid rubber bulbs or hollow rubber bulbs. Hollow bulb seals increase the seal flexibility in low head applications (typically less than 20 ft). Prolonged distortion of a hollow bulb seal, however, may result in permanent set of the bulb whereas a solid bulb seal will retain its round shape. Most bulb-type seals described above can be manufactured as hollow bulb seals. In addition to increasing seal flexibility, the hollow bulb will deform to provide a large area of contact against the sealing surface. At splices or joints, soft rubber plugs are inserted into the hole to seal them and to provide a full face for cementing or vulcanizing.
- *Protective cladding.* Seal bulbs are often provided with a cladding on the sealing contact surface, depending on type of service and the need to reduce friction. The clad material is integrated with the rubber seal during fabrication and is typically a fluorocarbon (Teflon®) material. Cladding is used for two major reasons:

    1. To reduce friction that can affect operating forces. The use of fluorocarbon cladding significantly reduces the seal friction coefficient, which can significantly reduce the gate operating forces and/or ballasting requirements.
    2. To reduce extrusion of the seal bulb under high head condition that may cause pinching of the bulb between the seal clamp bars and the sealing surface during gate operation.

    Before current fluorocarbon materials were available, brass cladding was used for the same purpose. Metal cladding (brass or stainless steel) is still available, but is not often used due to its high cost and difficulties in adhering metal cladding to the rubber substrate. Metal cladding is typically found only on seals in extremely high head installations to help reinforce the seal from extrusion under pressure.

- *Fabric reinforcement.* Fabric reinforcement, consisting of a mesh of polyester fibers embedded in the rubber, is sometimes provided in molded rubber seals to reduce creep and prevent extrusion failure of a seal. This is typically not required except in gasket type applications where high compressive loads may cause permanent deformation of a non-reinforced gasket or shear failure due to high compressive loads.

2.5.4.1 Manufacture

Different manufacturing processes give gate seals specific properties:

- *Extruded vs. molded seals*. Extruded seals are formed by extrusion through a mold whereas molded seals are cast in molds. Extruded seals cost less than molded seals, but molded seals are the preferred choice for hydraulic gate seals because their cross sectional dimension is more uniform over the length of the seal than those of extruded seals, and the physical properties of the molded seal material are superior to the extruded seal material, which makes them more rugged and durable over the long run. Fluorocarbon cladding and fabric reinforcement can only be provided in molded seal construction.
- *Seal corners and splicing*. Most seals require splices of some kind to obtain the necessary sealing perimeter. The splice can be on a 45 deg angle joining the two sides or a molded corner can be used to allow straight splices away from the corner joint. Splice joints can either be hot vulcanized or cemented (also referred to as cold vulcanizing). The hot vulcanizing process consists of securing the two splice ends in a mold and heating the splice filler rubber to high temperatures to form a bond. The process is most successful when done in the shop under ideal conditions. Hot vulcanizing can be performed in the field using electrically heated, portable splicing molds. These molds can be rented from seal manufacturers for the more common seal profiles. For best results, at least 6 in. of straight seal is provided on either side of the splice to provide adequate length for clamping during the vulcanizing process. Hot vulcanizing typically produces a bond at the splice between 35 and 50% of the seal strip tensile strength.

  When hot vulcanizing cannot be performed, cementing of the splice is the only other option available. A rubber cement is selected specifically for the rubber compound used. Cemented joints produce a substantially watertight seal at the splice and some bond strength, but the bond strength is not considered reliable. Cementing of splices should be performed after the seal is in place because the splice is not considered structurally capable of withstanding handling forces.

  Molded seal corners for numerous seal arrangements are available from seal manufacturers and should be used whenever possible. Available molded corner arrangements include seals of different cross sections. The manufacturer can often fabricate seal corners by hot vulcanizing if molded corners are not available. Cementing of corners should be avoided where possible because these areas are often high stress points and cementing is structurally unreliable. Many seal failures occur at cemented seal splices.

2.5.4.2 Mounting

Seals are typically clamped to the gate by bolting. The way in which they are clamped depends on the seal type used. Figure 2-58 shows some common sealing arrangements. The most common mounting arrangement for steel gates consists of clamping the seal between a painted carbon steel backing bar (welded to the gate) and a stainless steel or painted carbon steel clamp bar by bolting. Figure 2-59 shows examples for side and bottom seals on a radial gate.

2.5.5 Rigid sealing systems

Rigid sealing systems are defined here as sealing arrangements that are composed of relatively non-flexible (compared to rubber) metallic, Teflon®, or timber materials. Rigid sealing systems are used most often on slide type gates and on some types of wheel-mounted gates in which:

- It is difficult to gain access to perform seal inspection and replacement.
- Gates are fabricated as self-contained units including the gate leaf and sealing frame. Such gates include sluice gates and bonneted slide gates. Since the gates are fully fabricated and fit-up in the shop, much tighter tolerances can be achieved versus gates where the sealing plane must be installed, aligned, and embedded separately in the field.
- Flows are very high and the gate profile must be knife-edge (bottom seals on high-pressure gates) to produce a smooth jet to prevent cavitation and/or flow induced vibration.

The gate-mounted seal bars are typically made of a softer, low friction material with a highly polished surface. Machining tolerances are critical on gates of this type as there is no flexibility in the seals to accommodate waviness or discontinuities. In many instances, the sealing system also acts as the load-bearing surface.

The sealing surfaces are similar to those discussed above for flexible rubber sealing systems. Since rigid seals typically act as bearing supports for the gate, the reinforcing members provided behind the sealing surface plates are typically much stiffer than for the rubber seal plate.

Figure 2-59. Radial gate seals. (Courtesy of HDR Engineering, Inc.)

2.6 Gate operating systems

A gate operating system or hoist is designed to open and close the gate or to hold the gate in a desired position. Reliable gate performance requires that equal attention be given to all components of the gate operating system. The gate operating system may include:

- Gate attachment devices such as lifting lugs, hooks and pins
- Lifting chains, wire ropes, stems and lifting beams
- Hoist equipment consisting of hoist frame, cable/chain drums, drum shaft, gears and drive motor for wire rope or chain hoists; floor stand fitted with lifting nut and motor/hand actuator for screw stem hoists; and hydraulic cylinders, piping, and hydraulic power unit for hydraulic hoists
- Primary power source from the station service feed or from the local power grid and auxiliary power source from an onsite backup generator or from the local power grid
- Gate controls such as electrical pushbutton stations, gauges to monitor pressure in hydraulic and pneumatic systems, limit switches to control gate travel limits, overload protection, gate position indicators, and controllers to set gate position based on water level or flow releases.

It is very important that operation personnel be fully trained in the proper operating procedures for routine operations and during flood events. Also, operating personnel must periodically inspect, test, and maintain the operating system. See Chapters 3 and 4 for further information on operation and maintenance.

Failure to reliably open or close a gate can have serious safety and economic consequences. The inability to raise spillway gates quickly enough can lead to dam overtopping and breaching. Valuable water storage is lost if an outlet or spillway gate cannot be closed.

2.6.1 Function and application

Gate operating systems or hoists can be stationary or traveling and include various types of overhead cranes. Stationary (also referred to as dedicated) hoists have the advantage of being available at all times and can be set up for remote or automatic operation. Traveling hoists can be set up for remote operation for a single gate, but then a two-person crew is typically needed to move the hoist to the next gate. Table 2-2 lists operating systems commonly used for various gate types.

On projects with multiple spillway gates, one or two traveling hoists, sometimes referred to as “mules,” are common. The hoists are typically drum hoists that travel on rails mounted on the bridge deck. Moving the hoists is slow and can pose safety hazards to operation personnel. To reduce labor and improve reliability, most recent projects have stationary wire rope hoists for each gate.

2.6.2 Operating system types

2.6.2.1 Wire rope hoists

Wire rope hoists employ a rotating drum that winds and stores the wire rope as it lifts the load. The direction of rotation is reversed to lower the load. Stationary wire rope hoists are commonly used to operate spillway radial gates, hinged crest gates, and roller gates. The hoists are usually mounted on the bridge deck (directly over each gate) or just downstream of the bridge deck on a steel or concrete hoist platform resting on the spillway piers. A wire rope hoist system may consist of one or two drums, a drive motor, connection shaft, reduction gearing, and brakes (Figures 2-60, 2-61, 2-62, and 2-63).

If the hoist is located on the bridge deck, the drive motor can be located between the drums or at one end. When the bridge deck is used for access, the drive motor and drums are mounted on platforms with the connection

Table 2-2. Operating system and gate type.

Operating System	Gate Type										
	Bulkhead and Stoplog	Drum	Hinged Crest	Flashboards	Navigation Wicket	Floating Bulkhead	Inflatable	Radial	Roller Dam	Wheel and Roller-mounted	Vertical Slide
Wire Rope Hoist	●							●		●	●
Roller Chain Hoist	●							●		●	●
Link Chain Hoist	●							●	●	●	●
Rack and Pinion										●	●
Screw Stem (manual/electric)			●							●	●
Hydraulic Cylinder		●	●					●		●	●
Pneumatic Cylinder										●	●
Water Pressure (float chamber)		●				●					
Air Inflatable							●				
Float Operated								●			
Gantry Crane	●								●		
Monorail Hoist	●										
Jib Crane	●										
Mobile Crane	●			●		●					

shaft spanning the gate opening. Separate drive motors may be installed at each side of the gate with synchronized operation. In some cases where two motors are present, the gate can be driven by either of the two motors via a mechanical clutch.

Depending on the lifting weight, the number of wire ropes can vary from one per drum to as many as eight. Drum diameter should be at least 18 times the wire rope diameter. For hoists with multiple wire ropes, equal tensioning is critical to prevent racking of the gate (Figure 2-63). For radial gates, the wire ropes are most commonly connected to the upstream side of the gate leaf skinplate. The hoist drums should be located so that the wire ropes remain in contact with gate skinplate when the gate is closed. This will prevent vibration and debris from becoming trapped between the wire ropes and the skinplate.

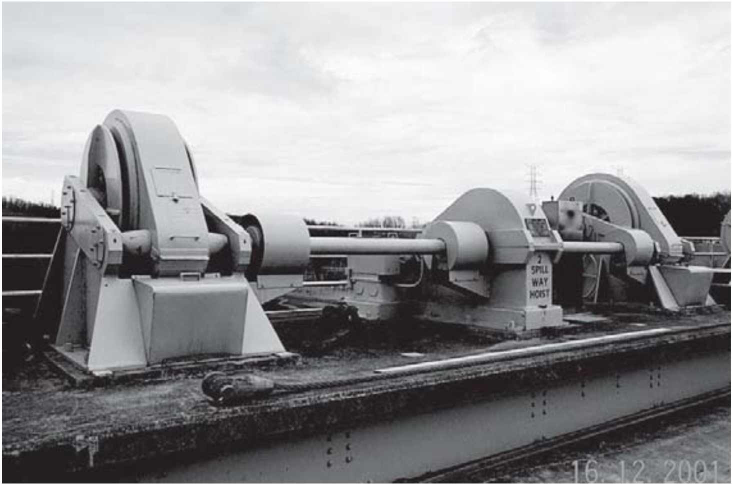


Figure 2-60. Drive, reduction gears, drums, and connection shafts (Courtesy of TVA).

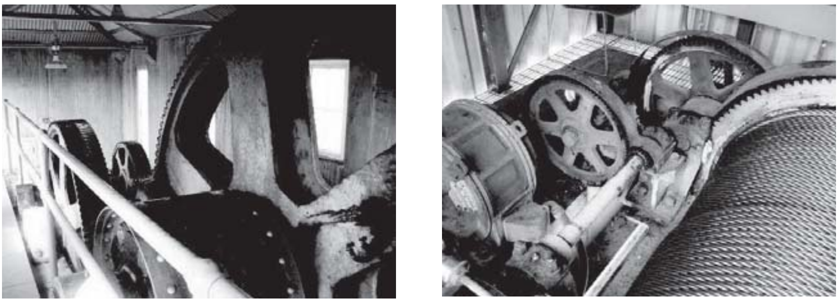


Figure 2-61. Exposed reduction gears.

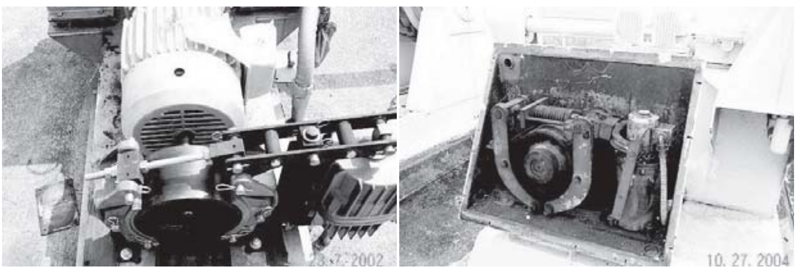


Figure 2-62. Brakes.

Figure 2-63. Multiple Rope Hoist.

Wire rope hoist controls can be designed for automatic or remote operation. However, manual controls are most common. Typically operation personnel activate the gate from the control panel on the hoist deck. The gate opens a pre-set distance and stops. To open or close the gate from this position, operation personnel must again activate the controls. A manual override allows for precise gate positioning.

2.6.2.2 Roller chain hoist

Chain hoists have the same components as a wire rope hoist except that the gate is raised by chains, either roller-type or link-type. Roller chain hoists employ a rotating sprocket that pulls the chain up on one side as it rotates and sends it out on the back side as it lifts the load. The direction of rotation is reversed to lower the load. (Figure 2-64). The roller-type chain is similar to a bicycle chain.

2.6.2.3 Link chain hoists

Link chain hoists employ a rotating wheel with pockets around the circumference for the chain links to sit in. The “chain wheel” pulls chain in on one side as it rotates and sends chain out the back side as the load is raised. The direction of rotation is reversed to lower the load. (Figures 2-65 and 2-66). The chain either winds around the drum or drops into a storage locker on the deck.

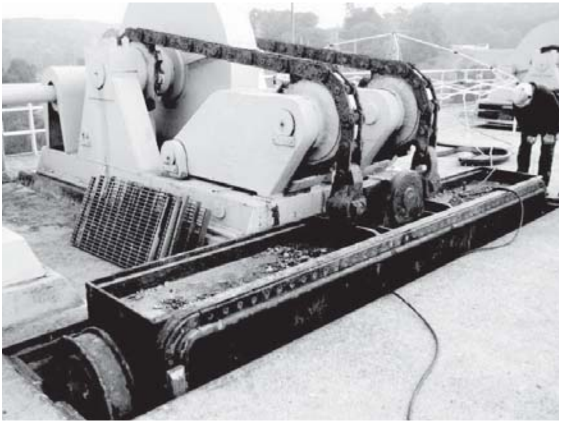


Figure 2-64. Roller Chain Hoist (Courtesy of TVA).

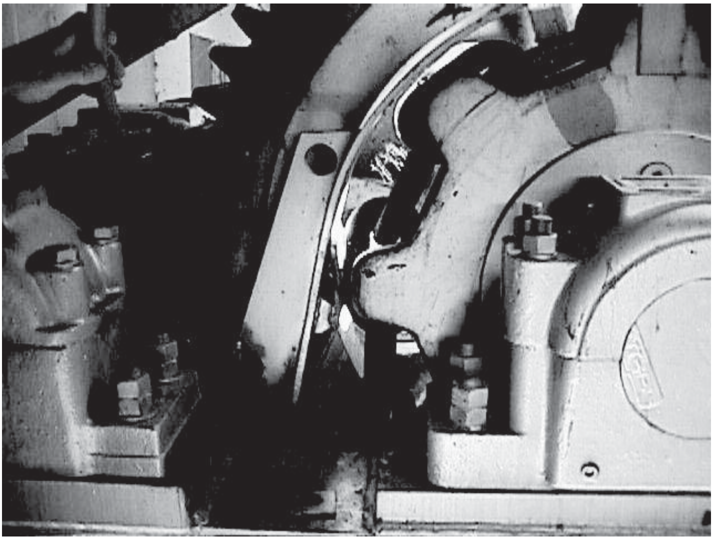


Figure 2-65. Chain Wheel (Courtesy of USACE).

Figure 2-66. Link Chain (Courtesy of USACE).

2.6.2.4 Rack and pinion hoists

Prior to the use of screw stem based operating systems, single or multiple flat gear racks mounted to the face of the gate (Figure 2-67) or gate stem(s) (Figure 2-68) were used in combination with deck mounted open gearing for most types of vertical lift gates. The rack teeth segments were manufactured to a repeating pattern to engage a deck mounted pinion gear that in turn was connected to a spur gear and either manually or electrically driven to raise and lower the gate. The advent of screw stems and more efficient enclosed gear drives made rack and pinion operating systems obsolete. Two of the more common types of rack-and-pinion hoists are single stem or double stem.

2.6.2.5 Screw stem hoist

Small slide gates are typically opened and closed by a screw stem operated by a handwheel or an electric motor operating system. Other types of smaller vertical lift gates, such as roller or wheel mounted gates, may also be operated by screw stem hoists. Depending on the width of the gate, a single stem or

Figure 2-67. Rack and pinion gate operator.

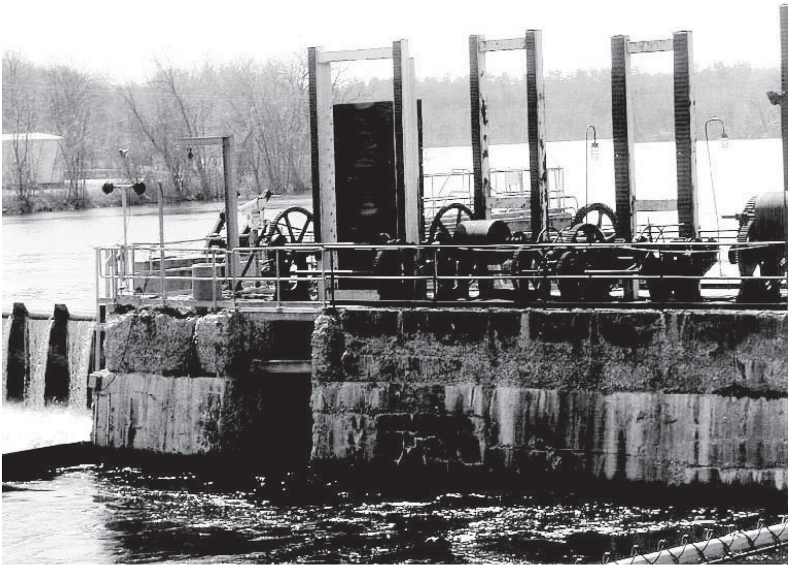


Figure 2-68. Rack and pinion gate operator.

twin stems may be used. In case two stems are used, the stems connected to each other by a line shaft for synchronization, with the common line shaft actuated by a common actuator. The screw stem either connects directly to the gate or through a series of coupled intermediate stems. The stems connect to the gate leaf via a thrust nut. Depending on the unsupported length of the stems, stem guides are used to prevent buckling during closure of the gate (Figure 2-69).

2.6.2.6 Cylinder hoist

A cylinder based operating system employs a hydraulic or pneumatic cylinder with a rod that telescopes out of one end. Hydraulic cylinder hoist is most common. The use of hydraulic hoists permits easier accommodation of any adjustments needed in gate speed or operating loads. Generally, the cylinder is suspended overhead with the rod fully extended. Gate attachment is at the extended end of the rod. In this configuration, with the rod fully extended, the gate is closed with no load on the cylinder. The gate is raised as the rod is retracted into the cylinder (Figure 2-70). Hydraulic cylinders are also used as gate hoists in arrangements with wire ropes. One end of the wire rope is fixed and the other end is attached to the gate. Fixed sheaves are located somewhere between the two points, and a moving sheave is attached to the end of the cylinder. The extension or retraction of the rod sheave shortens or lengthens the length of the wire rope and thereby raises or lowers the load. Gates operated by these systems are frequently held in place by a manually placed locking device to take the load off the cylinder. Locking devices are typically not used in conjunction with remote or automatically operated gates.

2.6.2.6.1 Hydraulic cylinder

A hydraulic operating system consists of one or more hydraulic cylinders, hydraulic power unit, and fluid lines between the cylinders and the power unit. Hydraulic operating systems are commonly used to operate many types of gates.

2.6.2.6.2 Pneumatic cylinder

A pneumatic operating system consists of an air cylinder, compressor and piping between the cylinder and compressor. Pneumatic systems are rarely used for gate operation because the combination of decreasing load when stroking the gate and the compressibility of air prohibit smooth gate operation.

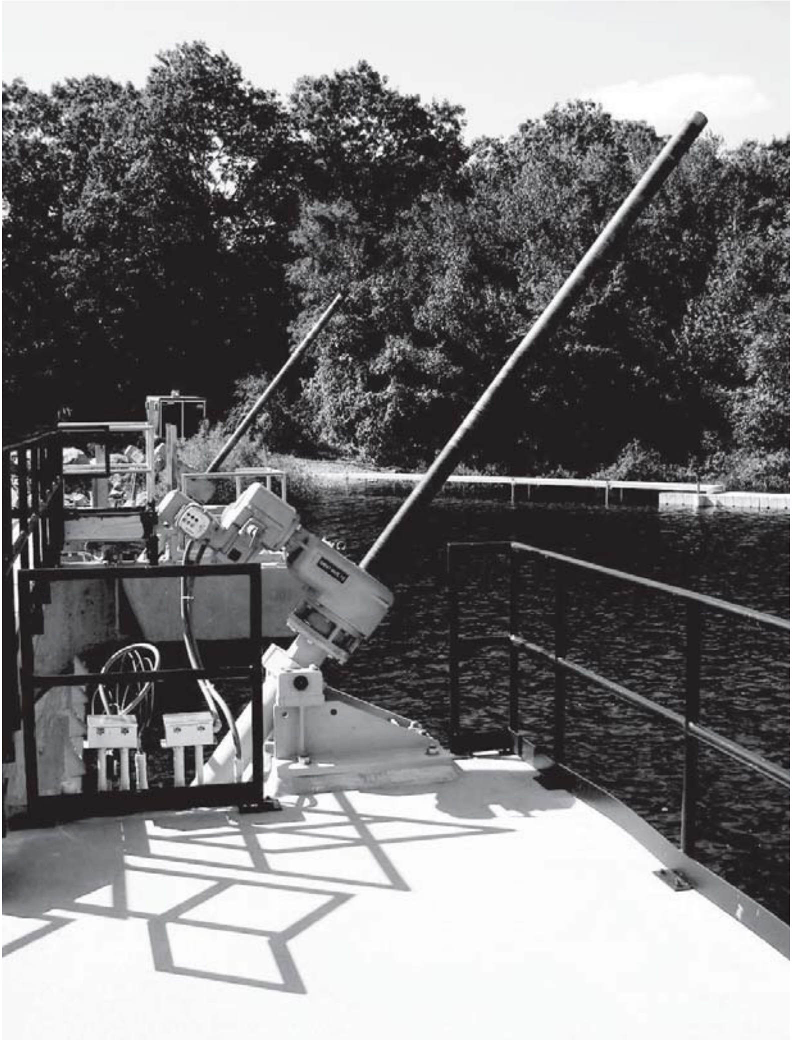


Figure 2-69. Screw stem gate operator.

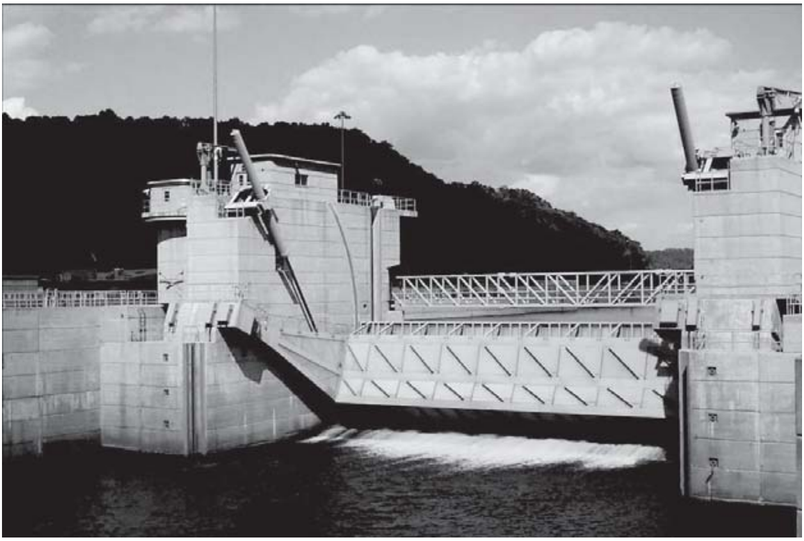


Figure 2-70. Radial gate with hydraulic cylinder actuator (Courtesy of USACE).

2.6.2.7 Water pressure

Drum gates and bear-trap gates are raised and lowered by differential water pressure buoyancy. A valve or slide gate is operated to admit water into the gate chamber to raise the gate and a drain valve is used to release water to lower the gate. The water intake can become clogged causing the gate to open unexpectedly. Debris can enter the drum gate chamber, clog the drain line, and prevent gate lowering. Seals on bear-trap gates can leak excessively so that sufficient water pressure cannot be developed to raise the gate.

2.6.2.8 Air inflatable

Air operated rubber dams have recently been used as crest gates and diversion dams. The rubber dam is inflated by an air blower or compressor and can be quickly inflated or deflated to capture runoff or release flood flows (Figure 2-71).

2.6.2.9 Float operated

Radial gates can be designed to operate by a float system, either to open to pass floods or to maintain a set lake level. The float system usually works in combination with a counterweight attached to the gates. Float operation is

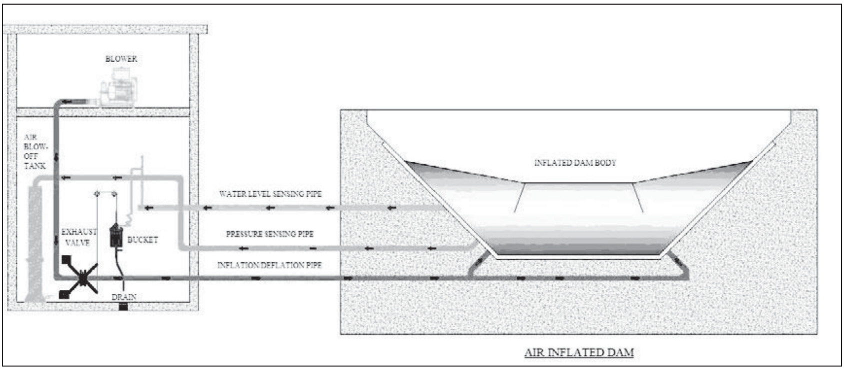


Figure 2-71. Mechanism for an air inflatable gate.

applicable to sites where reliable power is a requirement, but where reliable operation is a must. Balancing the gate and float system is difficult. The gate must be light enough to reliably open as the lake level rises, but heavy enough to fully close when the lake level drops. Excessive friction in trunnions, side seals, and float and counterweight sheaves can lead to operation problems. These systems can be retrofitted to use a small hoist instead of the float operator.

2.6.2.10 Gantry crane

A gantry crane is most commonly used for installing and removing maintenance gates such as bulkheads and stoplogs (Figure 2-72). A gantry crane is a hoisting machine that travels on parallel rails referred to as a "crane runway." The major components of a gantry crane are end trucks, legs, bridge girder, trolley, and hoist.

2.6.2.11 Monorail and other overhead hoists

A monorail is a single rail made of a standard wide flange or I-beam structural steel shapes or a welded composite section made up to be the similar configuration, but having a wider top flange. An overhead crane can be a monorail, single or double beam bridge, gantry, or jib crane. Overhead cranes may travel straight or follow curves and/or switches for changing direction. There are many variations of the basic configurations. Monorails may be suspended from fixed supports or serve as the track for the trolley travel on a jib crane or single-girder crane (Figures 2-73 and 2-74). A trolley, normally

Figure 2-72. Gantry crane.

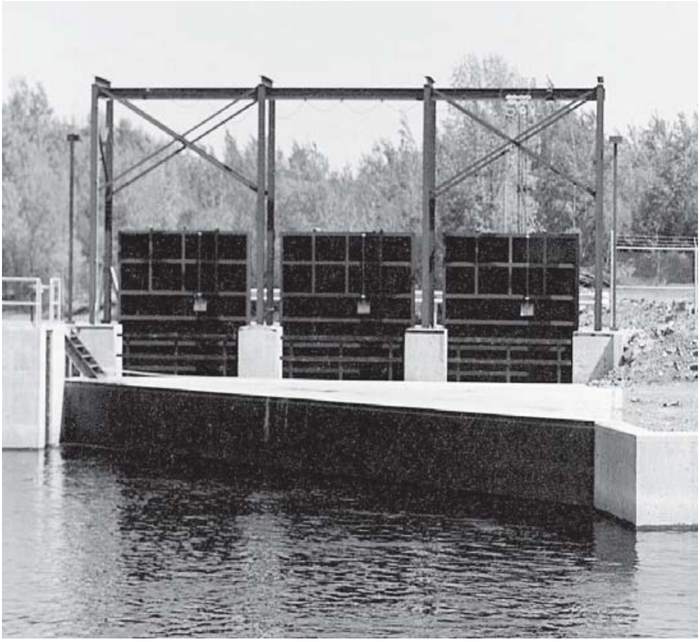


Figure 2-73. Hand-chain driven trolley on a monorail.

Figure 2-74. Motorized trolley on a monorail.

with two or more pairs of wheels, rides with wheels on both sides of the bottom flange of the monorail beam. Generally, a hoist is suspended from the trolley. The gate operating system for a monorail is defined as the entire monorail, trolley, and hoist. In some cases, there are multiple trolleys and hoists. They can operate independently or synchronously. In some cases, a lifting beam is used to bridge between two hoists on a monorail. The lifting beam would also be included in the monorail inspection. Monorail hoists use wire rope or chain, and may be manual or motor driven.

2.6.2.12 Jib crane

A jib crane is a device with a structure that has a pivot point at one end that supports a monorail and allows it to travel in an arc. There are several styles of jib crane mounting arrangements. They can be "free standing mast" type or "wall bracket or column mounted" type. The combination of pivoting movement and trolley movement allows the hoist and/or load to travel horizontally in two directions simultaneously and lift, transport, and lower a load at any point within an area covered by the monorail as it travels within the arc (Figures 2-75 and 2-76).

2.6.2.13 Mobile (alt. truck) crane

Mobile cranes are available in a wide range of capacities up to 500 tons and may be rented by water projects for maintenance purposes. Mobile cranes are typically used to install or remove bulkheads or stoplogs during infrequent maintenance outages.

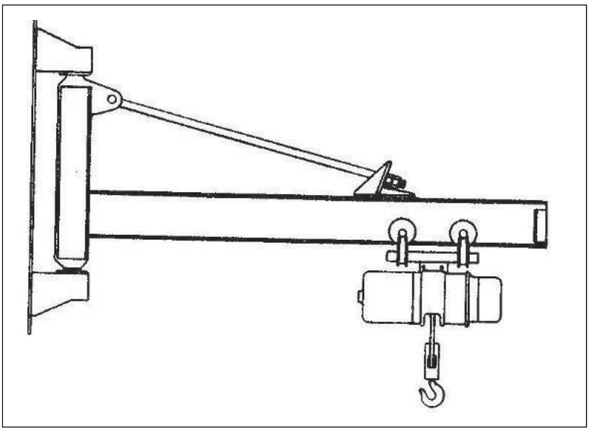


Figure 2-75. Wall or column mounted jib crane.

Figure 2-76. Free standing jib crane.

2.6.3 Common operating system electrical components

2.6.3.1 Electrical power

Stationary hoists are typically powered by conduit wiring via a station service circuit and associated motor control center. In some cases when the hoist is in a remote location, power is provided by the electrical distribution system which can include a step down transformer, metering, breaker or switch, a motor control center prior to the electrical hoist components. Normally there is a circuit breaker panel which allows electrical isolation and some device protection. In some cases there is a primary and secondary power feed, and on some hoists an emergency power supply such as a diesel generator. There are a variety of acceptable, NEC Code compliant, and reliable methods for providing electrical power to gate lifting devices.

Typical electrical equipment for hoists include:

- Controls
- Motors
- Wiring and conduit
- Electric supply
- Power feeds

- Power cords
- Auxiliary power
- Power disconnects and protection
- Grounding and lightning protection

Systems for connecting power to the hoist include:

- Conduit
- Power cords
    - Tag lines
    - Festoon systems
    - Hinged track cable carriers
    - Cable reels
- Strung wire conductor systems
- Rigid conductor bar or angle systems.

2.6.3.2 Controls

Hoist controls can be quite basic or can be quite complicated. Hoists may operate at the hoist location, near the hoist location, or far away from the hoist location. Control operation at the hoist location is referred to as “local control operation.” Control operation at any location other than immediately at the hoist location is referred to as “remote operation.” Controls can be a programmable logic controller or simple push buttons.

2.6.3.2.1 Programmable Logic Control (PLC)

Programmable Logic Control (PLC) devices are becoming more common for hydraulic gate operations. These devices can be connected to a wider area control system via a remote terminal unit (RTU) or simply provide standalone control for a single or multiple gate operation. PLCs are programmed with control algorithms and can be preprogrammed with opening and closing sequences, depending upon desired gate operations. PLC’s can be programmed to sound advanced alarms prior to initiating gate operation, or can be used in conjunction with instrumentation to record gate and hydraulic operations such as date and time of gate opening, actual gate opening, predicted gate flow, headwater elevation, tailwater elevation, date and time of gate closure, adjustments to gate openings and many other relevant data. The PLCs can be used in conjunction with site security devices, operate site lighting, and can even send alarms requesting assistance for a variety of operations and maintenance matters.

2.6.3.2.2 Local and remote

Many hoists have a two position control switch control switch, which allows for local or remote operation. Hoist controls may be operated by manual methods such as the press of a pushbutton or use of a switch, or hoist controls may be operated automatically by a programmable controller or via a remote termination unit (RTU) connected by telephone wire, radio, microwave, etc. to a central computer. The central computer may allow operation of many hoists at many stations.

A Local-Remote Selector Switch can be mounted at either location; however, most operators prefer the location to be remote from a control room instead of at the device to be operated. The reason is that sometimes the Operator locally will walk away from the device leaving the selector in the Local position and thus removing the ability to operate the device from the Remote location. One solution to that problem if the selector switch is mounted locally, make the selector switch a “Spring Return” type to the Remote position.

2.6.3.2.3 Load limit switches

Load limit switches are used to monitor the hoist load that is being lifted, and if larger than the load allowed by the load limit switch setting, the limit switch trips the hoist motor from operating. There are several types of load limit switches. The switches are calibrated to manufacturers’ standards and instructions.

Older limit switches can be unreliable and may provide a false indication of the hoist load.

2.6.3.2.4 Travel limit switches

Travel limit switches are used to limit the travel of the gate being raised or lowered. Once the limit is reached the device trips the hoist motor from further operation in the direction of travel. There are many types of travel limit switches, mechanical, electrical, and a combination of the two.

Older limit switches can be unreliable and may provide a false travel limit indication. Manual adjustment of the travel limit switches can frequently correct a false indication.

2.7 Auxiliary systems for gates

2.7.1 General

Auxiliary systems may include heaters, bubbler systems, lubrication systems, corrosion control systems, emergency lifting and closure devices, backup power supplies, emergency water release systems, etc. provided for specific design requirements for each water project. The following sections describe the most common auxiliary systems provided for water control gates.

2.7.2 Gate heaters

Some form of heating system, enclosure, or both may be provided for gates located in climates where extreme cold in winter creates icing problems and ice buildup on metal gate structures. Ice adds weight and can freeze seals to the sealing surfaces, making the lifting of a gate extremely difficult or impossible without breaking and/or removing the ice. Heaters are sometimes provided on the downstream side of the gate leaf or within gate bay wall cavities to maintain the metal temperature above freezing thereby preventing the formation of ice. The systems may include electrical heat tape within the seal design, heated sealing surfaces, or heated enclosures on the downstream side of the gate. Dams with multiple gates may have several gates designated as primary discharge gates for planned or emergency winter releases. These designated gates will normally have some form of gate heating to prevent ice buildup.

A common form of electrical resistance heater is a heating element installed in pipe or tubing cast into the concrete adjacent to the gate guides wallplates. Two types of heaters are used, one that heats the air of the tube that transfers the heat to the metal surfaces, and one that must be immersed in a liquid. Standard liquids include anti-freeze and ethylene glycols.

Hinged crest gates and vertical slide gates are sometimes equipped with enclosures to keep the entire gate ice-free. These enclosures are generally constructed of insulated wood or metal clad structures, with air inside the enclosure heated via fans or blowers.

For gates that have frequent winter operation, where seepage can result in ice build-up immediately downstream of the gate, structure heaters are sometimes employed. These heater systems consist of embedded tubing within structure walls and floors along the same principal of a residential forced hot water heating system for a house. A boiler provides adequate temperature and pressure of a liquid that flows through the valve-controlled tubing network. The system keeps the ambient surface temperature high enough to prevent ice build-up on exposed surfaces. System liquids generally use ethylene glycol anti-freeze.

2.7.3 De-Icing bubblers and agitators

Typically, deep water is generally a few degrees warmer than surface water. Flow agitation and upwelling of warmer water prohibits growth of sheet ice, and retards or prevents the growth of sheet ice against gate surfaces. Ice against a gate can prevent operation or increase structural loading on the gate itself.

Bubbler systems are provided on many projects to inject air into the water upstream of a gate to prevent formation of ice by inducing eddy currents that circulate the deeper water to the upstream side of the gate. Bubbler systems use compressed air injected into the water through a series of tubes with perforations to distribute air along the upstream face of the gate. These systems are often built into the sill of the spillway structures but may also be in the abutments or piers.

Where bubbler systems were not part of the original construction, a removable system may be added. In this instance, either a stationary or mobile compressor is used with a series of pipe wands inserted near the gate surface to keep water surfaces agitated sufficiently to prevent ice formation. This type of bubbler system requires complete removal before gate operation.

While bubbler systems are generally very efficient at preventing ice formation in cold environments (minus 10°F and higher), they are typically not effective at lower temperatures. This value can vary depending on water temperatures and depths at the gate, amount of air injected, etc.

In addition to compressed air fed bubbler systems, some sites use electrically driven motors attached to impeller or fan blades to circulate water from deeper within the water column to the surface.

2.7.4 Auxiliary power systems

Auxiliary power systems are provided at projects to operate gates in the event of a primary power loss in emergency situations. No grid power supply is immune from outage. Examples of emergency situations (where backup power may be required) are intense climatic events where heavy rains, snow, sleet, winds, forest fires, or other situations occur that damage primary power lines.

Auxiliary power systems provided for water supply or irrigation projects typically include engine-operated emergency generators capable of providing an alternate power supply to raise all gates. Backup power generators are normally diesel-fueled; however other fuel systems may be used. The auxiliary power system at a hydroelectric power project may consist of an emergency generator coupled with the power plant generators. Other plants may have diesel-powered cranes provided as a source to operate gates during power losses. Limited backup hoist capability can be provided by accumulators for hydraulically operated gates.

3 Gate Operation[1]

3.1 Introduction

Safe project operation is the goal of all owners. To accomplish this, a project dependent on proper gate operation should have an overall operational plan for the safety of the dam. The extent of an operations plan depends on the complexity of the dam itself. Factors such as size, hazard classification, number and type of gates and operating mechanisms, location, hydrology, river hydraulics, and economics should be considered. This chapter focuses specifically on the operational plan requirements specific to the gates.

3.2 Operational plan and water control manual

Hydraulic gates are the most common means by which operators regulate stream flow and assure safe project operation. A clear and well written operation plan and water control manual establishes the operation requirements, processes, necessary coordination with various authorities and operation procedures. An operational plan should document all aspects of the safe operation of a dam and the gates. If certain aspects of operation are addressed in project or other documents, they should be identified and copies should be included. In those cases where operation authorities are shared by two or more owners, (private, local government, state or federal) it is important that clear operations authority are written in the operational plan.

The safe operation of water control gates may involve adjusting the reservoir level, controlling ice and debris, periodic exercise, keeping records, and, in general, ensuring public safety. The water control manual should include instructions for normal project operations. Often operations personnel are located remotely from the project or spillway location and must rely on site personnel or video to confirm the gate has no possible physical interference with its intended operation. Maintenance of accurate records and communication of on-site conditions with remote operations personnel can be key to safe gate operation. Regardless of whether gate operation is frequent or not, project and public safety must be maintained. The manual should also outline the sequence of actions required during an infrequent event, such as a

[1] Portions of this chapter were extracted or adapted from FEMA 145 (sect 3.2).

large flood. Operational procedures to be followed during normal, flood, and emergency events should be readily available for use by the primary operators (remote or on-site) and by anyone else who might be called on to operate the gates. A periodic drill to verify knowledge of the operation procedures is suggested as a mechanism to confirm that the operation procedures are known by operations personnel and procedures are readily available. Additional topics may be covered within the manual or in separate referenced documentation. Periodic review and updating of the procedures is suggested as operation changes are adopted and gates and hoists undergo significant maintenance or replacement.

The language of the operations plan should be easy to understand, clear and concise. Though procedures are often expressed in engineering terms, these terms may not be completely understood by operations personnel. The language of the operational plan should be understandable by the operations personnel. The operation plan should have a table of contents which allows the operations personnel to find key information and procedures that may be needed quickly. Some owners have elected to place the operational plan on their intranet system so that it can be widely available in a "read only" form. This is a reasonable practice; however, during a flood event often there is a power outage and the internet, intranet or computer systems may not be functional, so hard copies of the operational plan at the dispatch operational facility and at the project or gate site are recommended. If the owner has adopted a central operations and maintenance facility approach, which would require the dispatch of an operator to the gate site, hard copies of the operational plan or electronic copies stored on the personnel portable computers should be considered.

These documents, which form the operational plan, should include, as a minimum:

- Spillway and outlet characteristics data (see Section 3.4)
- Instructions for operable mechanisms (see Section 3.5)
- Hydraulic openings and gate sequencing for normal and infrequent events (see Section 3.6.4)
- Hydrologic characteristics of the watershed (see Section 3.6.5)
- De-Icing and debris removal (see Section 3.7)
- Routine operation guidelines (see Chapter 3)
- Non-routine operation guidelines (see Section 3.8)
- Maintenance guidelines (see Chapter 4)

- Inspection guidelines (see Section 3.9 and Chapters 6 and 7)
- Emergency operations and notification guidelines (see Section 3.10)
- Training (see Section 3.11)
- Other (see Section 3.12)
- Conveyance systems (see Section 3.12.2).

3.3 Staffing

Project staff, experience of individual staff members, and the approaches used to accomplish operations and maintenance for projects has changed over the years. In general, the number of personnel at a project whose primary responsibility is operation of the dam has decreased and in some cases a remote operations strategy has been adopted. The determination of optimal personnel levels should be based on consideration of failure consequences, the relationship to other projects, response time, overall site safety, and safety considerations for personnel working at the site, watershed characteristics, and other relevant factors. Regardless of how a project is manned, it must be watched much more closely during unusual or infrequent occurrences that increase project risk. Such occurrences would include rapid reservoir level rise, large flow releases, and any compromise of the ability to hold the water level within normal operation limits.

The required level of operations and the amount and type of operations and maintenance training is a function of the project's complexity. Operator(s) should be trained in routine and flood event operations, safety issues that might arise during a flood event, and also must be made aware of other types of problems that could arise. Significant flood events can be very infrequent and less experienced operators may be unfamiliar with critical operations during these events. With good operational plans, coupled with effective training and situational drills, staff can be prepared for infrequently occurring operating conditions including extreme events, failure of gate components or remote gate controls, or the inability to access off-site instructions for gate operation and positioning. During the infrequent events, site personnel or dispatched personnel are often under significant stress and are required to multitask to accomplish the operations procedures. This is when mistakes are most likely or a required step is forgotten. The consequences of errors are usually greater too. During such events, there is usually no time to read a manual or a procedure; and they must rely on previous training and periodic drills. Typically training and periodic drills are done during normal operations periods and allow personnel to become familiar with requirements before the infrequent event occurs.

3.3.1 Unmanned

Some dams with gates are not manned. These dams are generally small and are capable of passing flood flows without gate operations. The industry trend is clearly to automate or to rely increasingly on on-call or visiting staff to reduce manpower at existing dams. It is likely that site staffing will continue to be reduced at many projects. Some unmanned dams require gate operation both for normal operations and infrequent events such as during low recurrence flood events. Some unmanned projects are remotely operated, and may or may not be monitored. Unmanned dams should be visited and physically observed regularly. This is most important when a significant rainfall or snow melt event is forecast, and during flood and high water level events. Problems must be discovered and addressed in a timely fashion. In some cases, the gate may be submerged and visual checks of the actual gate may not be possible. However, other visual indicators of possible problems include significant floating debris, adverse ice conditions, and other location-specific problems. In some cases, remote gates and hoists have been locked or made inoperable by vandalism.

3.3.2 Partially manned

A project is “partially manned” when person(s) are at the project less than full time. For example, an operator could be at the project 8 hours a day Monday to Friday, on a scheduled and/or temporary (on-call) basis. The operation may be limited to reading and/or verifying reservoir levels, etc. or to opening gates on request from a central dispatch center. Project personnel may be primarily focused on operation of the project and/or they may have other primary duties such as routine maintenance. It is important that the remote personnel be knowledgeable of all project operation requirements and be capable to recognize a developing issue or problem, that onsite personnel communicate regularly, and that they be responsive when adverse weather or other infrequent conditions exist. Also, it is important to schedule substitute coverage when personnel are on leave or are otherwise absent.

3.3.3 Fully manned

A fully manned project is staffed 24 hours per day, 7 days per week. This does not automatically translate into better operation. It is also dependent on the discipline, experience, training of the site staff and management of the site staff responsibilities. For example, the operator may monitor one or multiple projects in addition to being responsible for routine maintenance.

3.4 Gate characteristics

The spillway and gate characteristics, including operational limitations, environmental and downstream limitations or constraints, hydraulic limitations, potential impacts if gates are not sequentially or limited in their opening, can be obtained from a number of sources and should be maintained in the operational plan for ready reference. This information can be very important to reference or be aware of during an infrequent event or emergency. Operation plans in electronic form can be linked to allow for key reference information and data sources to be made readily available to operations personnel. Hard copies should have references and list the location where key information and data is located for reference. This background information and the source of this data should be clearly stated, including:

- Type and length of spillway
- Normal and surcharge water elevations, including freeboard
- Maximum observed flows and dates of occurrence (distinguish between snowmelt and rainfall), with appropriate comments if resulting from unusual conditions such as rapid warming or upstream dam failure.
- Gate sizes, configuration, and type of outlet
- Gate control devices, including details of primary and backup equipment
- Discharge curves or tables for gates
- Drainage systems and drain locations
- Downstream warnings, notifications, and impacts from gate operation (if any)
- Data sources
- Project records, such as design documents, “as-builts,” and construction photos
- Independent Consultant Safety Inspections (CSI)
- Supplemental Technical Information Document (STID)
- Special studies such as Potential Failure Mode Analysis (PFMA) and/or Fault Tree Analysis (FTA).

3.5 Gate controls

Gates may be opened on site or from an offsite location, remotely or automatically. The local controls should be located to allow the operations personnel to have safe access during an infrequent event such as a flood or after an earthquake. Local controls must be available if remote control does not open a gate, Operations personnel will need to be available for dispatch to the gate location to troubleshoot and operate the gate. If a known problem occurs during an infrequent flooding event exists, such as a walkway being overtopped as the upstream water level rises, an overtopping condition occurs in a low spot on the dam, or gate overtopping occurs, it should be noted in the operational plan. Some local problems may have been experienced in past operations, and it is important to note the problem in the operations plan and explain how it has been previously mitigated. In many cases, the issue has not been documented, and those operations and maintenance staff with experience from a previous flood or earthquake will know about an issue. During the preparation of an operation plan, it is important to gather relevant information from personnel who have experienced a previous flood or earthquake. Post event interviews are also recommended to assure that issues are written down and included in the operation plan.

Power outages are the most common problem encountered. Back-up generators or portable generators are often needed during the outage. The Operation Plan should clearly state how to assume and maintain local control during back-up generator and portable generator operation, as often the normal power circuits must be bypassed. Where manual hoist back-up is provided for in the event of motor or hydraulic hoist failure, manual hoist operation is a physically demanding activity, and the operations personnel dispatched should be physically able to do the required manual operation. The operation plan should describe the physical operation of the manual operations including number of revolutions, crank circulations, strength requirements, etc.

The operational plan should provide a complete control and operations diagram showing the location of the local control and how to access it, required hoist and gate component connections, and load ratings between components with, clear, step-by-step instructions for operating mechanisms. Even if the gate only has a manual operator without any back-up mechanism, the operational plan should have an operations diagram. The instructions should include sketches, drawings, and photographs to help identify specific handles, cranks, buttons, etc. They should also list the correct method to open and close guard gates, the correct use of gates during low and high flow, the openings at which excessive vibrations are experienced, the potential(s) for overheating of motor(s), and other operating problems related to specific gate(s). For hydraulic and electric gates, a schematic diagram should be provided showing each component (including back-up generators and other equipment) and its place in the operating sequence. Back-up generators and back-up equipment are often not at the gate locations, and clear instructions about where these are located and operations instructions for these components are also needed. Also, as stated in Section 3.6, the proper sequencing of gate openings should be included.

3.5.1 Manual gate operation

Manual (human powered) operation may be the only method of operation for some small gates. It is also sometimes a backup method for larger gates. For those hoists with a manual back-up method, it is important that the manual system be periodically exercised and verified to be in a working condition.

3.5.2 Local gate controls

Local controls located near the gate are most common. Local control may be a pushbutton station near or on the gate hoist, or a manual control method such as a hand crank or handwheel. This configuration allows the operator the best vantage point from which to observe the gate operation and to react to a problem with the gate, a problem upstream of gate, or a problem related to a discharge that may arise during operation. However, the use of local gate controls is often more labor intensive than the use of remote or automated controls, and may result in some operator safety risks, particularly during flood events. Local controls usually include a primary drive source, such as electric motor and redundant controls such as hand cranks. Use of local controls may also require starting a back-up generator and knowing how to route power to energize the hoist.

3.5.3 Remote operation

Remote controls may be operated on- or off-site. It is important that the gate operation not unexpectedly interrupt recreational activities immediately downstream or cause environmental damage. Despite physical barriers, warning signs, sirens, or announcements, people and animal life often occupy unsafe areas when gates must be opened. Visual confirmation is important. In some cases, delayed gate operations after warning horns have sounded are used, remote cameras are strategically located to allow remote operators to determine if people are downstream of a gate, or slowed gate opening operation or sequenced gate operations are required. For some projects, a local visual observation is required and a verbal "all clear" communication is made to the remote operator before the first gate opens. The communication link from the remote control station to the local gate hoist is a very important component of this system.

Potential downstream users can also be alerted to expect downstream releases by media announcements including website postings, local radio station announcements and newspaper notices. Mishaps, or near mishaps, where downstream public was unprepared for a gate opening are common. Safety is an important consideration when opening any gate and making a flow release and precautions must be observed.

3.5.4 Automated gate controls

Automated gate controls are increasingly common. These controls usually have a programmable logic controller (PLC) along with a supervisory control and data acquisition system (SCADA). It is important that operations personnel know when a gate is opening or closing, even when a gate is automated to open and close through a PLC or SCADA system. A warning or alarm notification should be sent to the operations center to alert operations and maintenance personnel that a gate is to be opened or closed, and appear on the SCADA control monitor. A delay may be included prior to remotely operating a gate to allow actual site verification that it is safe to release water downstream. In some cases, operator intervention may be needed to override the automatic function. Operations monitoring (including TV cameras) is needed. Often fencing and physical barriers are used to prevent people or animal access downstream of the gates.

3.5.5 Control access

The goal is to allow controlled access by authorized personnel while preventing unauthorized access by the public. Consider use of the following to control and monitor access:

- TV cameras for remote observation
- Motion detectors depending on location
- Electro-magnetic locks on hoists and gates
- Security fencing with a locked gate.

During infrequent floods or other unusual events, conflicting demands on their time may make personnel less available. The infrequent event may block access to the gate, to the gate controls, and to roads, and may also disrupt communications. Operators should be aware of access routes to the dam and spillway, on-site routes to the spillway controls, and known hazards and contingencies when normal access may be affected by flooding, road washout, snow and ice, high winds, and lightening.

3.6 Hydraulic capacities and gate sequencing

3.6.1 Hydrology

The operational procedures for a project are often a function of the watershed characteristics. For example, the seasonal reservoir level depends on requirements such as water supply storage (high pool level), flood control reservation (low pool level), or recreation (constant elevation). The prediction of a watershed's response to various types and durations of precipitation and the resulting runoff during a given season is generally based on historical records, which may be correlated to a mathematical model. Advance information on storms is generally made available through the National Weather Service (NWS) through normal weather reporting and prediction of local flooding based on storm predictions. These predictions include large storm fronts, local and regional thunderstorms, and rain-on-snow events. Runoff prediction data are obtained through precipitation gauges and upstream stream gages, and through communication with upstream dam owners or local personnel.

Limited information on reservoirs far upstream, regardless of whether they are large or small watersheds, often makes it difficult to predict their contribution to infrequent flood events due to limited information and faster changes in inflow and water levels. With dams in series, this may necessitate specialized operations to optimize the water level at each project. Models may be developed to estimate anticipated inflows and to manage reservoir storage and releases through gated outlets and spillways. Accurate prediction of storm events that would result in flood events enables more advanced planning for reservoir and gate operations. Often NWS predictions allow operations personnel as much as 24 hours advance notice and storm tracking devices such as Doppler radar allow more accurate prediction and measurement of strong storm activity within a particular watershed. Knowledge of rainfall and rainfall duration and how this rainfall data relate to the anticipated inflows and required outflows often dictates the implementation of operation procedures.

3.6.2 Hydraulic capacities

The hydraulic capacity of an individual gate, or of multiple gates, depends on a number of parameters, such as "hydraulic head," which is basically the difference in water elevations between the headwater and tailwater for a given gate position, position of the gate opening relative to the headwater level which determines orifice or weir flow, submergence of the gate opening by the tailwater, and shape and approach channel configuration upstream of the gate or gates. In some cases, physical obstructions in the upstream approach channel or tailrace can also affect gate discharge. The following sections briefly summarize some of the items that must be considered when determining the capacity of one or multiple gates operating for a given event.

3.6.3 Discharge outflow values

The discharge outflow values are a function of hydraulic head across the gate(s), from headwater to tailwater; consideration of hydraulic losses such as pipe sizes and gate openings; and potential gate opening limitations and restraints, such as the deck elevation above the gates and tailwater submergence of the gate opening, if any. These flows can be computed from standard engineering manuals and verified by actual stream flow values or modeling. These flow computations consider whether the gate is partially or fully open. For example, tainter or vertical lift gates will have full water contact on the upstream side of the gate and discharge as orifice flow until the bottom lip of the gate separates from the discharging water nap and pressure flow becomes weir flow. In some cases, the tainter or vertical lift gates discharge on a downstream surface that is flat, or slightly downward sloped, or the gate bottom sits on a weir or concrete ogee section. These flows can be calculated and provided in tabular and/or graphical form for both individual and multiple gates and should be included in the operations manual. It is standard engineering practice to note that these flows do not include the impacts of conditions such as ice or debris. Note that existing projects may have outdated tables that do not agree with modern computational methods. Nevertheless, this valuable historic information can be used for the operations, since the primary goal is to maintain a safe dam by flow regulation. This information should be tailored to operator needs and understanding.

Note that some historic practices used by long-time operations personnel may have been developed qualitatively rather than by quantification. Often the reasons why such undocumented practices are followed has become forgotten as one operator has passed it down to another operator. This has worked for many years successfully, but today this is not good practice and may be hiding some operation shortcoming or limitation of the gate(s) or hoists. Properly calculated gate hydraulic discharge tables and rating curves are needed and recommended. In some cases, physical and analytical hydraulic modeling should be considered for large spillways and critical situations where flood control is paramount. Recent hurricane and flood activity, and the resulting damages, have demonstrated the need for better understanding of hydraulics and flow regulation. Simple and concise flow tables and curves are essential for consistent and safe operation, even when they serve only as a backup to more advanced real-time computerized flow calculations. Emergency situations including flood, earthquake and other infrequent events are difficult times to be performing hydraulic and river regulation calculations. Modern computer methods allow for advance planning through simulations of postulated events, and these simulations can provide critical knowledge during a flood or earthquake event. The simulations can also provide the basis for an unexpected circumstance during the infrequent event. Some owners, especially large agencies, continuously make hydraulic release calculations during flood events. While this may prove advantageous, backup release plans should be available and ready if needed.

3.6.3.1 Normal operations

Normal operations of a project are intended to maintain a defined reservoir level in conjunction with agreed on downstream flow releases. In essence, "normal" refers to flow regulations related to common operating conditions seen on a daily, monthly or seasonal basis.

3.6.3.2 Infrequent operations

Infrequent operations include operations undertaken during flood and other rare events. Project personnel may be required to assume duties outside their normal roles and responsibilities in these situations. In these circumstances, the actual discharge capacity of the gate(s) is sometimes reduced by such elements as an increase in tailwater, adjacent gate influence, limitations of full gate opening, and/or obstructions such as an operating system or service bridge. The presence of debris or ice may require an operator to adjust the number of gates to be operated, or the opening at which a gate may be operated. Generally these limiting factors are predictable and their impact on capacity can be estimated using modern engineering methodologies. However, when these limiting factors are experienced during an infrequent event, their affect can be more uncertain. It is recommended that the gate discharge tables and discharge verified according to current practices, and that the table and curves consider not only the normal range conditions but also simulated conditions outside the normal operating range. A copy of the calculations should be included in the references for the operations plan.

Even with the best of documentation and clear hydraulic discharge tables and curves, the ability to do another check is very useful to decision makers during an infrequent event. The actual computer simulations are often maintained on an accessible computer system and are also referenced in the documentation. Hydraulic computer simulations require a specialized and highly trained specialist, and it is important that the documentation include actual specialist name(s) and phone number(s). In the event that a specialist has a change of employment status or retires, alternate arrangements should be made to assure specialist continuity. It is also considered good practice to periodically review flow management, and discharge tables and values, as a complete understanding is needed when an infrequent event is actually encountered.

3.6.4 Gate sequencing

The sequence in which gates are opened is generally based on a number of factors related to inflow and outflows from a reservoir. The sequencing should consider:

- Upstream and downstream impacts, such as flooding of structures and property and environmental affects
- The discharge capacity relationships between fixed spillways, gates, and other outlets
- Scour of tailrace foundation or channel soils (i.e., hydraulic run out, non-uniform flows)
- Maintenance of reservoir level
- Adequate safety factors such as freeboard
- Historic experiences and/or hydrologic studies of the watershed
- Gate availability (out of service gates).

3.6.5 Design hydrology

Design hydrology in the form of climatologic and watershed assessment and precipitation runoff modeling, and river and reservoir hydraulic modeling are key to understanding project normal and infrequent inflows and outflows. This modeling varies in complexity depending on the watershed size, river length, and number of upstream hydraulic structures and reservoirs. The project may include a reservoir or be a simple diversion or other hydraulic structure. There may be a dam with a spillway, fish facilities, powerhouse, pumping station or a lock. Each hydraulic structure is designed for normal river, stream or canal flows and, to varying degrees, for the infrequent flood and other high water level events. In the case of reservoirs, the hydraulic structure may be designed to accept predicted annual runoff and normal spring time high water events. These are the basis for planning normal and infrequent project operations including prediction of flood flows and project plans for passing these infrequent high flow events.

In larger river systems, a Federal agency such as the Corps of Engineers, Bureau of Reclamation, or the Tennessee Valley Authority (and many other river authorities) are responsible for the river regulation and flood management. These agencies work closely with local and state agencies and municipalities, and other project owners throughout the watershed drainage and river system to set requirements for project hydraulic operation during normal and infrequent operations. These Federal agencies have full time hydrologists who maintain complex watershed models and river hydraulic models to predict normal and infrequent operation for hydrologic events. These agencies often use routine analytical climatologic, hydrologic, and river modeling to predict an upcoming flood event days and even weeks in advance. However, even with the Federal flood management, project owners are responsible for the operations at their facilities, including local high runoff events that result from thunderstorms of unregulated stream tributaries that may enter the upstream river or reservoir. This responsibility requires project owners to understand hydrology and river regulation. In other words, project owners must understand the watershed and its runoff characteristics (whether snowmelt or rain); they must understand the surface water resulting under normal and infrequent climatologic circumstances; they must be able to predict and route the flow through the upstream river system and reservoir, and they must be able to regulate the safe passage of flows through the hydraulic structures, particularly the project gates, outlets, and spillways.

Many river, reservoir, and hydraulic projects have no mandated Federal watershed management or flow regulation by a Federal agency or a river authority. Owners of these projects will have the added responsibility to understand the hydrology of the watershed and stream(s) and reservoir regulation. These project owners must make storm and runoff predictions and regulate the safe passage of normal and flood flows. These owners will typically either have a hydrologist on staff, or will contract with a hydrologic consultant to assist with flow predictions and to develop watershed and other hydraulic models customized to the specific watershed characteristics; to stream and rivers within the watershed; and to the reservoirs and hydraulic regulation provided in the configuration of the outlet and spillways gates.

Operations personnel will use information from the U.S. National Weather Service, River Management Authorities, and the specific project hydraulic and hydrologic models and information to manage operations for normal flows, infrequent flood events and other infrequent flow-changing events. However, this may not be possible or economically feasible during extreme flood events, when prediction and early warning are needed for emergency preparedness, for controlled evacuation and shelter.

The Inflow Design Flood (IDF) is the hydrologic event that is used for determining a project's hydrologic adequacy. The IDF is the primary basis for spillway capacity, establishing storage and freeboard requirements, and evaluating operating rules. The IDF is derived through an assessment of site-specific flood hydrology and the safety, economic, and environmental risks associated with failure during an extreme flood. The nature of the "extreme flood" can vary widely depending on the location and/or the regulatory criteria. For some FERC-regulated projects, the regulated extreme flood can be as frequent as the 100-year recurrence interval event if incremental hazard assessments determine that a dam failure will not cause incremental downstream water surface increases of more than 1-ft elevation. Most Federal Projects, and some state-regulated ones, use the Probable Maximum Flood (PMF) as the basis for the IDF. It is important in characterizing the IDF that both peak flow rate and the volume of the flood be considered. At some projects (particularly flood reduction projects), the volume of the IDF can be more significant for project safety and adequacy than the peak discharge rate.

In addition to maintaining required stability and flood conveyance capacity, projects generally have some hydraulic benefits, e.g., flood control, water supply, hydropower, recreation, or navigation. In many cases, a project's purposes (and those benefits) are stated in the form of a project authorization, permit, or license. Some smaller reservoirs, ponds, and small hydraulic structures may not have formal authorizations, permits, or licenses, although the project's purpose may have been clearly stated when the project was originally planned or constructed. From time to time, a project's purposes change. For example, when pulp and paper mills or grist mills are abandoned, the project's works may be taken over for another purpose such as power production, recreation, or other public use. In many cases agricultural-related ponds and reservoirs may not have a formal authorization. Regardless of the authorization type, or even whether an authorization exists, it is important that the project owner comply with operation processes and procedures that result in safe project operations during normal and infrequent floods and other events. With those project benefits come impacts, which the authorization, permits, or license usually seeks to minimize or preclude, such as "lost valley storage" (which is the reduction in natural flood hydrograph attenuation that occurs with operation of a reservoir).

The Project authorization, permits, or License stipulation(s) can be defined in the form of a reservoir and project operation "rule curve." The rule curve defines the project operational requirements, including maximum/minimum reservoir operating elevations, and reservoir storage requirements based on the time of year and upstream hydrologic potential. If a project is operated in conformance with its rule curve, it will meet the authorization, permit, or license stipulations. As projects authorizations change or new permits are issued or are relicensed, the key elements of a rule curve may require changes. When changes are needed to the project operations or river regulation, past operations practices should be reviewed and the operations plan changed to agree with the revised requirements.

Rule curve purposes may include:

- **Flood control**. Flood control can include the project's reservoir normal storage and surcharge volumes, and prescribed release rates that support other project's rule curves (i.e., multiple projects within one river system that are operated in conformance with a "System Curve"). The flood control "purpose" is often inured from a combination of project reservoir storage and downstream levees. The Standard Project Flood (SPF) (see Section 3.6.5.1 for a definition of SPF) is normally numerically "routed" through the project's downstream reach during design. Boundaries are derived and obtained from that flood inundation zone. The inundation zones are usually owned outright, but are occasionally controlled with flood easements within which project boundary restrictions apply (e.g., no habitable structures allowed).
- **Irrigation**. Some project reservoirs serve the purpose of irrigation with a combination of storage and by pumping to canal delivery systems (wherein the rule curve satisfies canal intake or pump station water surface limits), or by releasing water for downstream irrigation uses.

- **Navigation**. Many of the larger river systems, such as the Mississippi River, have been developed with a navigation functional attribute. In these instances, the rule curve considers navigation functional criteria.
- **Recreation**. Project authorization may include a recreational component, which may have primary or secondary rule curve requirements.
- **Fish and Wildlife**. Project authorization may include reservoir and/or downstream flow requirements. These will often factor into the rule curve development. Many projects have undergone rule curve modifications to improve support fishery interests (e.g., Hoover Dam, Glen Canyon Dam, Columbia River system). As described below, making modifications to the original-authorization rule curve in support of more contemporary public demands such as water quality regime changes can be a long, difficult process with many diverse stakeholders.
- **Hydroelectric Power**. Projects with electric generation capacity generally operate the projects for electric power production within rule curve constraints. In these projects, the generation component of the rule curve is typically subservient to other project functional requirements such as flood control, fishery resource protection, other ecological and environmental protection, water supply, irrigation, and possibly recreation and should also be coordinated with upstream and downstream projects if they exist.

Consequently, project authorization functional requirements for both Federal and non-Federal projects generally come with the stipulations that: (1) the project must comply with existing project authorization criteria (rule curves), which govern reservoir and water passage operations, and (2) required flood control capability, which is an important and specific “benefit” of the project that usually takes precedence over other project benefits, such as power production, irrigation, and (during extreme hydrologic events) ecological criteria.

On rivers where more than one project is authorized or licensed, multiple projects are usually authorized in a manner that considers “coordinated benefits.” Rule curves for the individual projects are therefore formulated in a way that considers the other project’s capabilities and constraints. In other words, the projects’ authorized functional requirements may include criteria for flood control and/or in-stream flow controls that were a part of the original project’s authorization, balancing project impacts with benefits inured to the public (such as navigation, flood control, irrigation, or coordinated power production).

Computerized or manual project controls are used to regulate powerhouse, outlet, and spillway discharge. Normally, projects are required to pass minimum in-stream flow rates and to have minimum design discharge rates. Both minimum flow and minimum design discharge rates are determined as part of the in-stream flow analyses and hydrologic assessment.

Rule curves for older projects may have been changed or modified to reflect better hydrologic understanding, to accommodate development that have changed storm runoff, to accommodate regulatory and public processes, and to better regulate or meet the original project authorization or license. Many projects had a single purpose at the time they were authorized for construction. Over time, other beneficial purposes—undocumented as rule curve changes—may have been formally or informally added to the project. For example, recreation and environmental beneficial uses can result in rule curve modifications to limit seasonal reservoir level changes.

The original intent of the rule curve is to either: (1) meet the project authorization, permit, or license criteria (e.g., projects developed with flood control purposes as their primary authorized use), or (2) provide the primary beneficial use and make up for "lost valley storage" (to reduce impacts that may have been an outcome of the original beneficial use, if other benefits such as power production, or navigation were added to the primary project authorization, permits, or license intents).

Understanding the basis of the project design hydrology, assumptions, and operating criteria is crucial in assessing operational decisions. Changing the design hydrology and rule curve can be an arduous process that can potentially affect many parties or stakeholders, including upstream/downstream dam owners and public and private entities. Many project authorizations, permits, or licenses have attendant channel improvements (e.g., levee systems up and/or downstream of the project). A rule curve regulates project discharges and downstream water levels. This keeps water levels within levee system design limits and provides protection to downstream communities, agriculture, environmental habitat and other users.

In some cases, the project authorization, permits, or licenses will not have a specific rule curve, but will state the required reservoir levels, a reservoir volume for flood retention, minimum and maximum allowable project discharge values, and other operation restrictions in a single term, e.g., a "water pact," "flow easement," or "storage water right." Also, some small water projects may not have a formal authorization, permit, or license. Environmental requirements may also dictate flow and storage regime requirements and seasonal or monthly changes. These documents can also be expressed in a reservoir or flow rule curve. For simpler, single-purpose projects like an agricultural pond or simple community water storage reservoir, this may not be necessary; however, existing and new ponds and small community reservoirs are increasingly being used for storm water retention. Rule curves vary widely in terms of complexity depending on the project purpose, size, project complexity, and Federal, state, and local mandates and requirements. The owner is responsible for the design hydrology and must ensure that the project can safely pass normal and infrequent flood flows. Maintaining operational flow regulation gates, reservoir outlets, and spillways are fundamental to this responsibility.

3.6.5.1 Original design hydrology

Design hydrology may originate from many sources and techniques. However, with the development of regulatory and institutional frameworks for dam authorization and assessment, certain standardized techniques have emerged. For example, many relatively small projects (with commensurately small risks associated with flood-induced failures) the hydrology is based on U.S. Department of Agriculture (Soil Conservation Service [SCS]) rainfall-runoff modeling methodologies. Such methodologies were typically used in conjunction with a Precipitation-Frequency Atlas for rainfall depth, duration, and distribution. The Precipitation-Frequency Atlas series formed the basis for runoff potential estimates for precipitation events as rare as 1:100 years (e.g., NOAA Atlas II for the Western 17 states). Direct analysis of recorded streamflows, such as from U.S. Geological Survey (USGS), is also an approach to developing probability-based inflow design floods, but the availability and length of streamflow records limit the usefulness of this approach.

For larger dams, the design flood is typically not based on probabilistic rainfall or streamflow estimates. For example, Federal agencies such as the USACE and FERC use the concept of the Standard Project Flood and Probable Maximum Flood in design of high hazard hydraulic structures. Definitions of the SPF and PMF normally used in their derivation are:

Standard Project Flood (SPF) – The most severe combination of conditions considered reasonably characteristic of the river basin.

Probable Maximum Flood (PMF) –	The most severe combination of conditions considered reasonably possible for the river basin.

Neither the SPF nor the PMF is linked to a specific recurrence probability. Attempts to assign probabilities to specific PMF or SPF estimates are subject to great uncertainty because these floods and their assumed contributory rainfall events are so much larger (in many cases several times larger) than observed events at or near the site. Furthermore, estimated relationships between the PMF or SPF and the 1-percent probability event vary with region, basin size, and hydrologic characteristics.

Like the frequency-based design floods, the SPF and PMF are generally estimated through rainfall-runoff modeling and are presumed to result from the Standard Project Storm and Probable Maximum Storm respectively. The Probable Maximum Storm is a site-specific event that represents the critical configuration, in time and space, of the Probable Maximum Precipitation (PMP) for the project's region. The PMP is generally derived from the National Weather Service Hydrometeorological Reports (HMR's) such as HMR-57 for the Northwest states (Figure 3-1). The HMR's represent the regionalization and optimization of historically critical hydrometeorological events in a region. In some cases, site specific studies have been used instead.

Generally, project authorization or licensing comes with the requirement that the project is able to reliably pass floods up to the SPF rate and for the dam to remain structurally safe up to the PMF. However, FERC for example allows for application of less stringent criteria to some dams if the downstream hazard assessment reliably shows there is no loss of life resulting from a dam failure, or if incremental hazard assessments show that dam failure would not result in a downstream water surface increase of more than 1 foot. Alternatively, a risk-informed approach may be considered in decisions regarding whether actions are needed to prevent overtopping and other potential failure of dams due to overtopping.

Projects are usually provided with a Spillway Design Flood value based on the SPF and PMF. In river basins with only one project, or with upstream project(s) that have little or no reservoir regulating volume, the SPF and PMF rates are unregulated inflow rates to the project reservoir; that is, the SPF and PMF are not reduced by upstream control. In river basins with multiple projects, each project is usually allocated, on authorization, a defined flood control storage space. The SPF and PMF are then the regulated rates (the

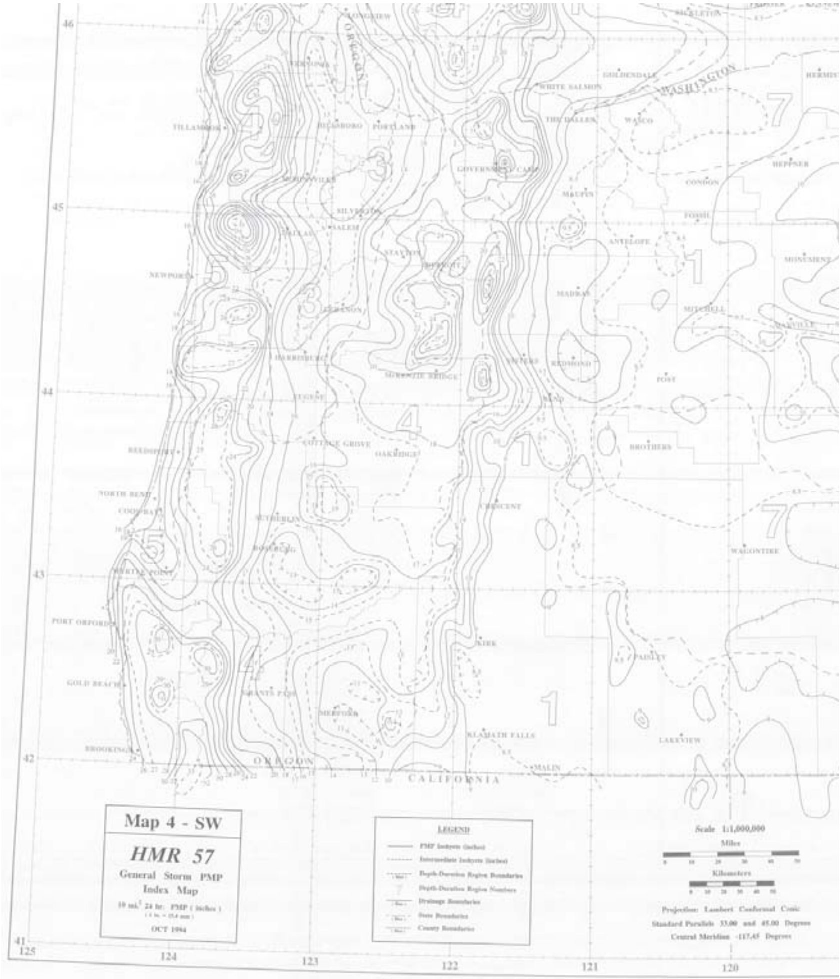


Figure 3-1. Example map of HMR 57. (Courtesy of NOAA)

reservoir outflow rate is reduced from the unregulated SPF and PMF rates). The storage space is then further allocated in discrete time intervals in accord with a "Flood Control Operating Plan" that is established as a function of the forecast seasonal runoff volume and the time of the year. The operating plan also defines reservoir releases during the flood control period (in forecastable hydrologic regions, frequently with a significant snow melt hydrologic component) and other flood and functional requirement control criteria in accordance with forecast hydrologic events and authorized use demands.

The consideration of risk posed by a postulated failure for a particular dam during extreme flood loading conditions may also affect the Inflow Design Flood determination. For example, a dam that might be considered a high hazard dam under normal flow or moderate flood conditions might become submerged during the SPF or PMF, so that its failure poses no additional risk beyond the economic loss of the structure itself. In that situation, a smaller Inflow Design Flood could be selected based on an incremental hazard assessment and determination of the acceptable economic risks.

3.6.5.2 Changes to original design hydrology

Changes to the original design hydrology can result from a variety of conditions, including:

- The addition of new upstream storage may reduce hydrologic functional requirements at a downstream project. This can occur when new reservoir storage is developed or storage is increased upstream of an existing project. The addition of upstream storage increases regulation through the addition of river system storage and coordinated operation of multiple reservoirs. The improvements can effect reductions in the peak discharge of the SPF and PMF at downstream facilities. For example if there has been an increase in upstream storage, a new flood routing calculation of the flood of record could result in a decrease of a project's maximum inflow, storage requirements and spillway design flood flow.
- Improved coordination among multiple projects within a river system could decrease the peak inflow at downstream projects and the storage requirements at any given project.
- Advances in hydrologic forecasting and improved modeling of runoff in a river system could reduce PMPs and reduce project peak and average inflows, and the flood hydrograph timing and volume. For example, the development of new or additional reservoir storage and/or additional

stream gage record information has been used to better predict and route the flood of record. An improved rainfall-runoff model can be the basis for updating the maximum probable inflow into project reservoirs. The advent and refinement of the Streamflow Synthesis and Reservoir Regulation (SSARR) Model has, in some multiple project river systems, resulted in improved runoff forecasting and reduced peak reservoir inflows and reduced quantity of predicted flood flow. The resulting affect after routing through the downstream projects is a reduction in peak spillway outflow requirements. Changing environmental requirements (e.g., increased in-stream flows for fishery and ecological enhancement) could result in changes to upstream reservoir storage requirements. Depending upon the timing of the changes to the reservoir storage requirements, changes may result in an increase or decrease in reservoir storage for flood control and result in a change to the project rule curve.

- Development encroaching into a river flood plain may not be politically controllable. Flooding causes shoreline damage and inundation, and can result in significant economic consequences and possible loss of life. In some cases levies and other manmade structures can be constructed within the floodway to protect the flood plain encroachment. Other steps can be used such as to require increased upstream flood storage or alternate flood improvements. Examples of encroachment include development of homes, recreational facilities, and industrial development within the floodway. Often, such changes are measured in terms of Population at Risk (POR). When floodplain encroachment requires added flood regulation, the result is a modification of the rule curve (e.g., lowering the reservoir's maximum pond elevation to add flood storage and protect the economic or urban encroachment.

Note that development of increased upstream storage, and coordination and runoff management improvements, generally decreases the original project rule curve restrictions. However, societal maturation in the form of expanding towns, suburbs, and recreational demands, combined with increasing expectations that dams will meet increasingly stringent environmental goals, may result in rule curves closer to a more natural flow regime during non-flood periods and more stringent flood control during flooding. Some communities and regional governments are requiring increased flood water retention with water retention ponds and other drainage control facilities. It can be expected that increasing multiple purpose water demands and societal demands for improved flood regulation will required continued changes to rule curves. For example, current power production, recreation use and irrigation may need to change in response to public demands for increased flood protection or reservoir storage/releases supporting environmental needs. Changes to Federal project design hydrology will likely stem from Congressional action and will conform to societal expectations for changing water use priorities. Non-Federal project design hydrology changes would likely be under the purview of the U.S. Army Corps of Engineers, the Federal Energy Regulatory Commission, or the state dam safety office after a thorough finding of fact and significant stakeholder review and response. Boundary water hydrologic changes could result from a treaty change or accommodation.

3.6.6 Hydrologic analysis and hydraulic calculations

River basin flows resulting from snow and other precipitation events are routed using complex engineering models from the top of the drainage or river basin through the many natural stream reaches, through reservoirs, dams, and hydraulic structures until the river reaches its confluence with another stream or river, or the ocean. These computer models simulate various normal and extreme flood events and calculate water levels for various stream flow conditions from minimum to flood flows. For example, the U.S. Army Corps Hydrologic Engineering Center has developed its Hydrologic Engineering Centers River Analysis System (HEC-RAS) computer modeling and computational system, which computes natural and man-made river system in one-dimensional, steady and unsteady state flow hydraulics and water surface profiles.

Once flow requirements are known for a particular project, the hydraulic configuration can be determined. Project flow regulation is generally accomplished at dams and other hydraulic structures with openings of a certain size or configuration such as a round or square orifice, or ungated overflow weir. Where more significant hydraulic regulation is needed; gates and valves are used. Most commonly for dams and reservoirs, a spillway is used to hydraulically pass and regulate project flow. Spillway flow can be either weir flow (also called “open channel flow”) or orifice flow; hence, different methods must be applied to determine the hydraulic characteristics and flow amount for an ungated or gated spillway. In some cases an ungated emergency spillway is used when the flood flow exceeds the flow capacity of the normal project spillway.

As a bottom opening gate opens, it forms an orifice defined by the level of the weir or sill, the sides of the gate opening, and the bottom of the gate. Typically this opening is rectangular. This is called orifice flow or pressure flow. As the gate opens the bottom of the gate will eventually clear the water surface. Once the bottom of the gate clears the water surface, this is referred to as weir flow. An ungated spillway will always be weir (open channel) flow. To regulate flow from a gate it is necessary to calculate how the flow varies with gate opening and also how the flow varies as the upstream water surface rises. Variables that must be taken into consideration for estimating the spillway flow include:

- Headwater level (upstream water surface level)
- Upstream head on the gate opening, if submerged
- Tailwater level and possible tailwater submergence
- Shape of spillway crest or weir
- Height of gate opening.

The headwater level or upstream water surface level is the reservoir level at the dam or in the reservoir upstream of the gate. In orifice flow, the water level at or near the gate will typically be the headwater level, but once open channel flow is established as the gate bottom clears the water surface, the headwater level is actually a distance upstream of the gate.

The shape of the spillway crest is one of the key factors that affect the shape of the water surface profile over the spillway. The most commonly used spillway crest shape is the ogee shape because it provides highly efficient discharges. The ogee shape approximates the lower nappe of a jet-flow over a sharp-crested weir to minimize the sub-atmospheric pressure. The ogee shape is determined based on the design head of the spillway. The method to calculate flow based on an ogee shape is illustrated in the Corps of Engineers, HEC-RAS Hydraulic Reference Manual, Chapter 8, Modeling Gated Spillways, Weirs and Drop Structures.

Hydraulic calculations for both the overflow weir flow condition and the orifice flow condition are discussed below. There are many hydraulic reference documents, laboratory reports, and books. Five reference documents are cited below and are frequently used when preparing spillway, weir, and other hydraulic calculations:

- *Design of Small Dams*, U. S. Bureau of Reclamation, Third Edition, 1987; available on-line at http://www.usbr.gov/pmts/hydraulics_lab/pubs/manuals/SmallDams.pdf
- *Davis' Handbook of Applied Hydraulics* (Davis and Sorensen; V. J. Zipparro editor-in-chief) 4th edition, McGraw-Hill, 1993
- *Hydraulic Design Criteria,* U.S. Army Corps of Engineers Coastal and Hydraulic Laboratory, Engineer Research and Development Center Waterways Experiment Station (ERDC-WES), 1987; available on-line at http://chi.erdc.usace.army.mil/hdc
- *EM 1110-2-1602 Engineering and Design-Hydraulic Design of Reservoir Outlet Works,* U.S. Army Corps of Engineers, Engineering Manuals, 1980; available on-line at http://140.194.76.129/publications/eng-manuals/
- *EM 1110-2-1603 Engineering and Design-Hydraulic Design of Spillways,* U.S. Army Corps of Engineers, Engineering Manuals, 1990; http://140.194.76.129/publications/eng-manuals

The USACE Engineer Manuals-Hydraulic Design of Reservoir Outlet Works and Hydraulic Design of Spillways, provide detailed discussions, explanations, and examples of hydraulics and hydraulic computations.

3.6.6.1 Weir flow condition for gated spillway

When an open gate, tailwater, or other obstruction does not project into the flow over the spillway crest, a weir (open channel) flow condition is formed at the gated spillway. Open-channel hydraulics applies to this flow condition.

3.6.6.1.1 Water surface profile

The water surface profile of the discharging water from the headwater level to the tailwater level is also called the nappe. Once the gate bottom clears the nappe, an open channel flow condition exists, which is similar to an uncontrolled overflow spillway. The water surface profile over an uncontrolled ogee spillway has been hydraulically modeled by numerous hydraulic laboratories and presented in numerous project-specific articles. The water surface profile over an uncontrolled ogee spillway was developed by the U.S. Bureau of Reclamation (USBR) based on experimental results by Bazin and Scimemi.

The Bureau of Reclamation Design of Small Dams, Chapter 9, Section 9.11 "Discharge Over and Uncontrolled Over-flow Ogee Crest" defines the elements of napped-shaped crest profiles. The coordinates of the upper and lower nappes for uncontrolled overflow ogee crest with various upstream and downstream face slopes are illustrated in the Davis' *Handbook of Applied Hydraulics*. The water surface profile for some other types of overflow spillway crest shapes can also be found in the USACE ERDC-WES *Hydraulic Design Criteria*.

3.6.6.1.2 Abutment and pier effects

The abutments and piers at a gated spillway cause contraction of the flow, resulting in a decreased spillway discharge capacity. The abutments and piers also affect the upper nappe profile. Nappe profiles are generally higher near piers and lower near the center of the gate opening. The upper nappe profiles under the abutment and pier effects are presented in the USACE ERDC-WES Hydraulic Design Criteria. The term "effective length" is used to define the weir length taking into account the level of contraction caused by the abutments and piers. Effective length is determined by:

1. Total length of the spillway
2. Alignment of the abutments and piers
3. Location of the piers
4. Shape of the pier nose
5. Thickness of the piers
6. Head
7. Approach velocity.

The method to determine the effective length using the above parameters is illustrated in the USACE ERDC-WES Hydraulic Design Criteria, and the USBR Design of Small Dams.

3.6.6.1.3 Spillway capacity

Under weir flow conditions, the spillway hydraulic capacity is determined by the discharge coefficient, the effective length of the spillway, and the total head on the spillway. The discharge coefficient is affected by several factors:

1. *Approach flow depth*. As the ratio of the approach flow depth to the total head increases, the discharge coefficient also increases.
2. *Upstream face slope of the spillway*. An inclined upstream face can either increase or decrease the discharge coefficient, depending on the ratio of the approach depth to the total head and the degree of the upstream face slope.

3. *Total head.* A total head less than the design head results in a decreased discharge coefficient due to positive pressure on the spillway crest. A total head greater than the design head results in an increased discharge coefficient due to negative pressure on the spillway crest.
4. *Tailwater condition and submergence.* When the tailwater level rises to a point that it reduces the discharge over the spillway, the spillway is considered to be under a submergence condition. Under such condition, the discharge coefficient of the spillway decreases as the submergence gets greater.
5. *Downstream profile of the spillway.* The downstream apron or obstruction can cause back-pressure against the flow going over the spillway and decrease the discharge coefficient.

The impact of the above factors to the discharge coefficient is depicted in a series of graphs in the USBR *Design of Small Dams*. For larger spillways with multiple gates, the spillway capacity is often determined using a physical hydraulic model.

3.6.6.2 Orifice flow condition for gated spillways

An orifice flow condition is formed when the bottom of an open gate or other obstruction is below the nappe surface or headwater level. It is important to consider drawdown effects when evaluating if an obstruction will results in orifice flow. Two types of orifice flow conditions are discussed below, low-head and submerged orifice.

3.6.6.2.1 Low-head orifice

A gated ogee spillway with a partially opened gates discharges as an orifice under low heads. The discharge through the gate opening is determined based on the discharge coefficient, the effective length of the spillway, and the total head over the top and bottom of the gate opening. The discharge coefficient is affected by the configuration of the spillway crest, the type of the gate, the position of the gate, the approach flow condition, possible submergence, and the downstream conditions. The method to determine the discharge coefficient and discharge capacity for a gated ogee spillway under an orifice flow condition is illustrated in the USBR *Design of Small Dams*.

3.6.6.2.2 Submerged orifice

Underwater gates, such as sluice gates, work similarly to submerged orifices. The discharge through a submerged gate opening is determined based on the orifice discharge coefficient, shape and dimension of the gate opening, and the head difference between the headwater and the tailwater. The tailwater condition can cause the orifice to be fully or partially submerged. The method to determine the orifice discharge coefficient and the discharge capacity through a submerged gate is illustrated in the USACE ERDC-WES *Hydraulic Design Criteria*.

3.6.6.3 Aeration

Cavitation damage on a spillway ogee, weir, or resulting from the gate discharge can be a very complex process. There has been considerable research on cavitation damage. There are five dominant factors which contribute to the potential for damage: (1) cavitation index, (2) flow velocity, (3) material strength, (4) impingement, and (5) operating time. Flow obstructions that have not been designed for energy dissipation or cavitation should be avoided. Prediction of cavitations damage is difficult and research is incomplete. The current state-of-the-art is a combination of physical and numerical modeling, analytical estimation, and prototype experience. Hydraulic physical modeling can improve predictability and confidence in a selected cavitation mitigation measure.

One mitigation method to reduce and possibly avoid cavitation is aeration of the water as it passes over the spillway or weir, or as the flow is discharged from the gate opening. "Cavitation damage results when the gas and water vapor-filled void is swept from the low-pressure into an adjacent higher pressure zone that will not support cavitation, causing the void to collapse" (from Hydraulic Design of Spillways, USACE). Aeration is one of the most effective measures to avoid cavitation damage caused by high-velocity flows. Insufficient aeration on the spillway surface can result in flow instabilities that cause undesired effects such as fluctuation in the flow, rapid pressure changes, sub atmospheric pressures and changes in the shape of the nappe profile. The amount of air required for aeration is affected by the head over the top of the gate, the head on the center of the gate, the gate opening, and the reduction of pressure of water to be maintained beneath the nappe.

3.6.6.4 Oscillation

Oscillation and vibration can occur due to insufficient aeration under high-velocity flows. It is a common concern for rubber dams due to the flexibility and light weight of the rubber material, and also due to the fact that the crest gates operate under harmonic conditions. A fin (or deflector) structure is usually installed on the upper part of the rubber dam to overcome the oscillation problem. Fins can also be installed on crest gates in combination with aeration of the nappe to reduce the tendency of this occurrence. The water surface profile over an uncontrolled ogee spillway was developed by the USBR based on experimental results by Bazin and Scimemi.

3.6.7 Hydraulic tables and event calculations

Spillway and/or sluice discharge tables (Table 3-1) are usually developed for gate operations at each dam. The values in these tables are calculated to determine gate positions needed to pass a required discharge at a given headwater elevation (Table 3-2). The specific gate arrangements are optimized to prevent significant cavitation from developing in the structure immediately downstream from the gate as well as the tailrace area downstream of the dam. Hydraulic model studies are typically developed before the dam is constructed to determine the optimum gate size, weir, and spillway apron profile, gate opening sequences, and the specific position of each gate that will prevent the described cavitation from developing (Figure 3-2).

During flood events, the discharge flow rate that is required may be communicated from a central authority to the dam operation staff, which performs needed gate operations. Locally, operations staff monitors the rising reservoir levels. In some cases, the gates may be operated remotely and reservoir levels may be monitored remotely. Typically, forecasting models and programs are used to determine the amount of predicted headwater elevations and reservoir inflow and required discharge flow rates corresponding to a given rainfall event.

The dam operator must be aware of the procedures to follow in the event of lost communications and rising reservoir headwater level. These procedures are unique to each dam. Without these procedures the operator may make an incorrect decision that causes unnecessary downstream damages or endangers the dam by raising the reservoir level.

3.7 Loss of outflow capacity

The designed hydraulic capacity of the gate may not be available for many possible reasons. All possibilities should be considered. The following sections describe a number of the more common possibilities.

Table 3-1. Spillway discharge (cubic feet per second)

Arrange-ment No.	Headwater Elevation 860.0	860.1	860.2	860.3	860.4	860.5	860.6	860.7	860.8	860.9	861.0	861.1	861.2	861.3	861.4	861.5	861.6	861.7	861.8	861.9	862.0	Arrange-ment No.
1	50	50	50	50	50	55	55	55	55	55	55	55	55	55	55	55	55	55	55	55	60	1
2	100	100	110	110	110	110	110	110	110	110	110	110	110	110	110	110	110	120	120	120	120	2
3	160	160	160	160	160	160	160	170	170	170	170	170	170	170	170	170	170	180	180	180	180	3
4	210	220	220	220	220	220	220	220	230	230	230	230	230	230	230	240	240	240	240	240	240	4
5	270	270	270	280	280	280	280	280	290	290	290	290	290	290	300	300	300	300	300	310	310	5
6	330	330	330	330	340	340	340	340	350	350	350	350	380	360	360	360	360	370	370	370	370	6
7	390	390	390	390	400	400	400	410	410	410	410	420	420	420	420	430	430	430	430	440	440	7
8	440	450	450	450	460	460	460	470	470	470	480	480	480	490	490	490	490	500	500	500	510	8
9	500	510	510	510	520	520	530	530	530	540	540	540	550	550	550	560	560	560	570	570	570	9
10	540	540	550	550	560	560	560	570	570	570	580	580	590	590	590	600	600	600	610	610	610	10
11	810	820	820	830	830	840	840	850	860	860	870	870	880	880	890	890	900	900	910	920	920	11
12	1100	1110	1120	1130	1130	1140	1150	1160	1170	1170	1180	1190	1200	1200	1210	1220	1230	1230	1240	1250	1250	12
13	1390	1400	1410	1420	1430	1440	1450	1460	1470	1480	1490	1500	1510	1520	1530	1540	1550	1560	1570	1580	1590	13
14	1680	1700	1710	1720	1730	1750	1760	1770	1780	1800	1810	1820	1830	1840	1850	1870	1880	1890	1900	1910	1920	14
15	2230	2250	2270	2280	2300	2320	2330	2350	2370	2380	2400	2420	2430	2450	2470	2480	2500	2510	2530	2550	2560	15
16	2780	2800	2820	2840	2870	2890	2910	2930	2960	2970	2990	3020	3040	3060	3080	3100	3120	3140	3160	3180	3200	16
17	3320	3350	3380	3400	3430	3460	3480	3510	3540	3560	3590	3610	3640	3660	3690	3710	3740	3760	3790	3810	3840	17
18	3900	3890	3880	3910	3940	3970	4010	4040	4070	4100	4130	4180	4190	4220	4250	4280	4310	4340	4370	4400	4430	18
19	4490	4430	4380	4420	4450	4490	4530	4570	4600	4640	4670	4710	4740	4780	4810	4850	4880	4920	4950	4980	5020	19
20	5070	4960	4880	4920	4970	5010	5050	5090	5140	5180	5220	5260	5300	5340	5380	5420	5460	5490	5530	5570	5610	20
21	5710	5690	5680	5760	5840	5920	6000	6090	6170	6250	6330	6360	6350	6330	6320	6300	6280	6260	6230	6210	6190	21
22	6340	6410	6480	6600	6720	6840	6980	7080	7200	7320	7440	7460	7400	7330	7250	7180	7100	7020	6940	6850	6760	22
23	6980	7130	7290	7440	7600	7750	7910	8070	8230	8390	8550	8570	8450	8320	8190	8060	7920	7780	7640	7490	7340	23
24	6980	7130	7290	7440	7600	7750	7910	8070	8230	8390	8550	8620	8590	8560	8530	8500	8460	8430	8390	8350	8300	24
25	6980	7130	7290	7440	7600	7750	7910	8070	8230	8390	8550	8670	8740	8810	8870	8940	9010	9070	9140	9210	9270	25
26	6980	7130	7290	7440	7600	7750	7910	8070	8230	8390	8550	8720	8880	9050	9210	9380	9550	9720	9890	10,080	10,240	26
27	6980	7130	7290	7440	7600	7750	7910	8070	8230	8390	8550	8720	8880	9050	9210	9380	9550	9720	9890	10,080	10,240	27
28	6980	7130	7290	7440	7600	7750	7910	8070	8230	8390	8550	8720	8880	9050	9210	9380	9550	9720	9890	10,080	10,240	28
29	6980	7130	7290	7440	7600	7750	7910	8070	8230	8390	8550	8720	8880	9050	9210	9380	9550	9720	9890	10,080	10,240	29
30	6980	7130	7290	7440	7600	7750	7910	8070	8230	8390	8550	8720	8880	9050	9210	9380	9550	9720	9890	10,080	10,240	30

Source: Courtesy of TVA

Table 3-2. Spillway gate arrangements.

Arrangement Number	Gate Number			Arrangement Number	Gate Number		
	1[a]	2	3		1	2	3
1	0	0.1	0	26	5.0	5.0	5.0
2	0	0.2	0	27	5.0	5.0	6.0
3	0	0.3	0	28	5.0	6.0	6.0
4	0	0.4	0	28	6.0	6.0	6.0
5	0	0.5	0	30	6.0	6.0	7.0
6	0	0.6	0	31	6.0	7.0	7.0
7	0	0.7	0	32	7.0	7.0	7.0
8	0	0.8	0	33	7.0	7.0	8.0
9	0	0.9	0	34	7.0	8.0	8.0
10	0	0.5	0.5	35	8.0	8.0	8.0
11	0.5	0.5	0.5	36	8.0	8.0	9.0
12	0.5	1.0	0.5	37	8.0	9.0	9.0
13	0.5	1.0	1.0	38	9.0	9.0	9.0
14	1.0	1.0	1.0	39	9.0	9.0	10.0
15	1.0	1.0	2.0	41	9.0	10.0	10.0
16	1.0	2.0	2.0	41	10.0	10.0	10.0
17	2.0	2.0	2.0	42	10.0	10.0	12.0
18	2.0	2.0	3.0	43	10.0	12.0	12.0
19	2.0	3.0	3.0	44	12.0	12.0	12.0
20	3.0	3.0	3.0	45	12.0	12.0	14.0
21	3.0	3.0	4.0	46	12.0	14.0	14.0
22	3.0	4.0	4.0	47	14.0	14.0	14.0
23	4.0	4.0	4.0	48	14.0	14.0	16.0
24	4.0	4.0	5.0	49	14.0	16.0	16.0
25	4.0	5.0	5.0	50	16.0	16.0	16.0

[a] Figures in columns under each gate refer to gate opening indicator reading.
Source: Courtesy of TVA

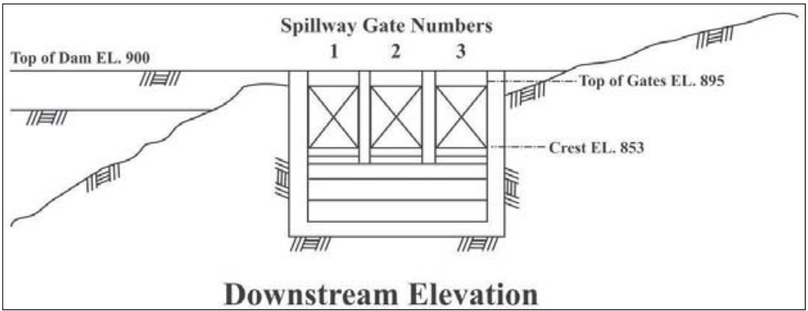


Figure 3-2. Location of spillway gates.

3.7.1 Obstructions

Obstructions such as debris or trash and ice must be considered, since a partial or full blockage of the fixed and/or gated sections of the dam can result in decreased flow capacities. Build-up can prevent gates from opening or partially or completely block gate openings. The gate type and size has a significant impact on its ability to effectively manage and pass obstructions. Deep gates are typically ineffective in handling obstruction when partially open; however, they are very effective at sluicing sediment. The effectiveness of the radial and vertical gates often depends on the open clearance between gate and the deck once in the fully open position. Surface type gates such as bottom hinged gates, vertical top sluicing gates, inflatable bladders and (to a lesser extent) radial and vertical roller or slide gates can be very effective at handling obstructions. Some items to consider for minimizing or reducing obstructions include:

- Gate sequencing operations to direct flows and obstructions to large unobstructed openings
- Directing personnel on site with support equipment, such as clams and hydraulic and pole chain saws, to cut or redirect debris within the gate opening
- Directing personnel on site with heaters, and hot water and steam equipment and accessories for ice removal
- Often partial concrete walls or beams are placed upstream of gate openings to direct floating ice away from gate openings
- When a new or rehabilitated gate system is being completed, making changes that can reduce or minimize debris problems, e.g., raising the height of the deck above the gate
- Eliminate any catch points on the gate, guides and approaching walls, ceiling and floor

3.7.1.1 Debris

If gate operation is regularly impeded by debris, an assessment should be made of ways to improve debris handling such as by installing log booms or by using surface skimmers. Great care must be taken to ensure that submerged large debris does not become wedged into a deep bottom discharge gate opening that would prevent the gate from properly opening or closing. While drum gates can effectively pass debris, they also present the potential for operational failure due to debris or sediment blockage of the inlet or outlet for the float chamber, which could prevent the raising or lowering of the gate.

3.7.1.2 Alignment

Debris and ice build-up can result in gate misalignment due to uneven lifting due to changes in the center of gravity or weight build-up, jamming between the guide and the gate. Differential movement can cause the gate to get stuck and prevent full opening and closing.

3.7.1.3 Concrete expansion

Alkali-aggregate reaction can reduce the width of the gate opening. The resulting loss is unlikely to have a significant impact on flow capacity, but it can prevent movement of the gate.

3.7.1.4 Ice

Gates that must operate in colder winter climates generally require more maintenance and attention due to freeze-thaw and icing. Ice can prevent or hamper gate opening and repositioning, reduce discharge capacity, or damage gate components. The proper functioning of gate winter equipment such as gate or gate guide heaters and enclosures, de-icers, and ice removal techniques may be necessary for the gate's reliable operation (see Chapters 2, 5 and 7). There may be circumstances where a gate is entirely blocked by ice. This possibility should be considered and its impact evaluated to determine if winter gate operations are critical to public and project safety. Some items to consider regarding ice are:

- Gate blockage is generally a function of the ice thickness, ice jams, reservoir configuration, and the size of the gate, particularly during the initial runoff. Ice has a tendency to break and disintegrate as velocities of flows increase.
- For critical components, such as the hinge area and seals, ice may must be continuously mitigated or removed before gates are operated. This removal can be done by electrical, steam, or manual means. Equipment maintenance and operational checks, and adequate deicing time should be scheduled in advance of anticipated gate operation for the necessary deicing procedures.
- Installation and operation of specialized deicing equipment, such as aeration systems, heated gate enclosures, heated sills, heated side plates

and heated arms, or a combination of deicing methods, may be necessary. The type of components and the maintenance of deicing systems is generally determined by Owner's experiences.

3.7.1.4.1 Ice loads

Ice loads on a gate are often difficult to estimate. However, based on engineering data from various technical sources, it is not uncommon to estimate a force of 5,000 lb per linear foot per depth of ice for gates at the water surface. This value compares to a value of 62.4 lb/ft for water without ice. Even though the full force of ice is often not on the gates, owners should take precautions that the force of ice at the top of the gate does not exceed that of design hydrostatic loading

Ice loads frequently vary from year to year depending on thickness and other factors. Reservoir ice cover is often broken during changes in reservoir levels during normal project operations, and in some cases this can result in ice jam build-up along the dam and spillway face. Ice formation should be monitored throughout the winter as there will often be formation changes from year-to-year depending on wind, reservoir flows, temporary freeze-thaws, rain on snow events, and the onset and timing of the freshet (run-off from spring thaw). Ice loads are not confined to the top of the gate, but may occur in the area between the piers and the arms, and between the sill and the gate. It is not uncommon for ice to form at the sills where the gate has a curvature or the seals leak.

Ice build-up on the gate can also affect the ability to lift the gate. One side of the gate structural frame can become iced while the other side is ice free, creating an unbalanced hoist load. Often when ice and snow build up is commonly experienced on a gate's structural frame, preventative measures are installed, such as temporary or permanent covers or insulated boarding, and heat is introduced between the ice prevention enclosure and the gate structure.

The impacts of ice hitting a partially open gate are often similar to that of debris. It is recommended that, at least during initial ice breakup, flood waters be allowed to pass through fully open gate(s).

Sometimes a reservoir is surcharged to pass ice over the top of gates during initial runoff. This practice can work, but also can result in ice damage to the downstream structural members of a gate.

Although the ice problems shown in Figure 3-3 probably represent the extreme, such conditions must be considered when evaluating ice loads and their passage during runoff. Ice on gate arms may occur as the result of freezing spray when a gate is opened even a little (Figure 3-4). The ice results in loads on members and adhesion between piers and gates.

3.7.1.4.1 Ice removal techniques

Ice removal can be on-going during the winter months, but may increase as inflow increases. Since ice loadings may hinder operation of hydraulic gates, deicing mechanisms such as aerators and heaters are used throughout the winter months.

For gates that will not need to be operated on short notice, complete ice prevention and continued de-icing operations may not be desirable due to expense. However, cost savings that result from not de-icing must be weighed against the eventual cost of de-icing prior to operation and against the costs resulting from ice loading that can damage structure components. Potential savings will vary based not only on the inflow characteristics and degree of icing, but also the dam configuration. For example, dams with fixed overflow spillways in conjunction with gates may have a lower risk of discharge complications due to ice than a dam that has all gated outlets. Often icing problems are due to gate leakage that results in ice formation alongside seals, arms, and the sill.

Where there is some flexibility in the timing of winter gate releases, various ice removal techniques may be employed. These include mechanical methods such as ice chipping, sawing, and auguring, and the use of hot water or steam. Regardless of the method used, personnel safety must remain a primary concern. Working around ice is very dangerous and extreme caution is required at all times. Conditions can change at any time while working to remove ice. A safe means of access such as the use of personnel harnesses and ropes, proper ladders and, platforms, and adherence to owner safety policies and state and Federal safety regulations is mandatory standard practice. For gates with downstream ice build-up or difficult downstream access, it is common to use hot water pressure washers or steam to remove ice from gate

Figure 3-3. Icing of spillway gates.

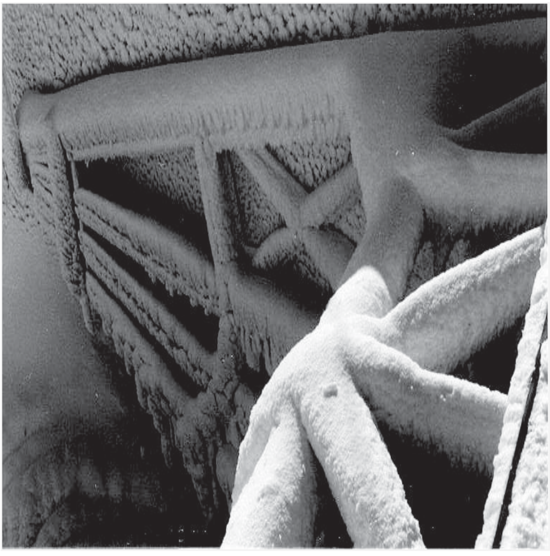


Figure 3-4. Ice on gate arms.

guides and gate surfaces. Special-length extension wands can be fabricated to allow most ice removal from an overhead deck surface.

3.7.1.4.2 Ice load monitoring

Ice monitoring can be done by electro-mechanical means, such as load cells that measure the depth and pressure of ice, or simply by operator observations. The latter method is more commonly used. For projects that are remotely operated, cameras are useful to visually check ice on the gate and upstream surface. Cameras may also be used to check ice from underwater.

Hoist loads may also be monitored during gate raising, particularly as part of spring runoff. These loads can be monitored by hoist load cells. Regardless of the measurement used, if the hoist mechanism indicates an abnormal load, the operation should cease and be investigated. The problem may be ice or another problem.

3.7.2 Non-serviceable gates

If one or more gates are out of service, the impact will vary. Nevertheless, in all cases, it is important for all gates to be returned to service as soon as possible. The impact of the gate outage on operation of the dam should be carefully assessed, whether it is due to a hoisting problem, a gate repair, or routine maintenance. In all cases, the potential impacts of non-serviceable gates should be anticipated. Examples include the inability to lower the water level when needed or unstable flow patterns through the remaining gate(s). A plan should be developed that addresses safe operation of the dam while a gate is inoperable. For example, interim or emergency measures might include opening the non-serviceable gate with a chain fall instead of a standard hoist.

3.7.3 Outlet gates

Because of their limited discharge capacity, outlet works generally present a smaller dam safety risk. The risk may be significant for a small watershed or where outlet gates are the only means of discharge. Also, if stuck open they can cause a significant unscheduled flow release resulting in a large economic loss, degrade water quality, or cause other environmental damage, especially if the outlet is near the bottom of the pool.

3.7.4 Ungated

Ungated spillways may be operated in conjunction with gated outlets or as an emergency outlet. Ungated spillways are designed to perform in one of three primary ways:

1. The elevations of fixed crest, gravity-operated, concrete spillways and chutes are generally set to operate before, during, or at a predetermined reservoir level.
2. Emergency spillways are generally set to operate once the normal project spillway is at full capacity and the reservoir has reached a predetermined flood level, but do not operate during normal reservoir operations. These spillways are not constructed for frequent use. In order to reduce cost, some damage to the overflow section and/or tailrace may have been deemed acceptable in the design and construction but the primary dam elevation is to remain intact.
3. Emergency spillways that are not operated except for extreme flows and are allowed to wash out sections of embankment in a controlled manner and release reservoir water. These spillways are generally fuse plugs or partially reinforced embankments. These last resort systems will often result in damage to portions of the dam and to downstream areas.

Regardless of how the ungated spillway was originally designed to perform, gated flow is often modified to avoid or minimize the uncertainty of an uncontrolled release over an ungated or emergency spillway. It is very important that the risk inherent in changes to the operational plan be recognized and properly assessed. New or unfamiliar operations and maintenance personnel can cause an uncontrolled release if they are not made familiar with the operations plan.

3.8 Non-routine operation

The non-routine operation of gates may include release or reservoir storage of water for emergency or comparable uses (e.g., extreme flood events, exceeding design limits, special environmental releases, or long duration operations).

3.8.1 Infrequently used gates

Depending on the hydraulic and operational characteristics of the project, one or all of the gates may be used infrequently. Possible reasons for this may include: the use of gates may be operationally unnecessary except in extreme floods; gates may not be in use to avoid adverse downstream consequences or to avoid adverse reservoir surcharging. In these cases, when gates have been infrequently used, there can be a concern that they may not operate correctly when needed; thus periodic exercising of them is important (see Chapter 8).

3.8.2 Controlled releases

A number of circumstances can result in the need to change project operations, e.g., continued encroachment in the downstream flood plain by the development of properties. These conditions must be periodically assessed for their impacts on the operation plan and dam safety, e.g., for their tendency to reduce reservoir surcharge capacity.

3.8.3 Emergency lifting procedures and equipment

Emergency lift procedures and equipment vary depending on the type of gate and gate access. Emergencies include failure of the hoist system, misalignment, debris, icing, concrete growth (via alkali-aggregate reaction [AAR]), or other conditions that may prevent a gate from opening. The operational plan should include an assessment of the availability and condition of required equipment, and the operating staff's familiarity with its use, and with appropriate loading tolerances. An important part of the assessment is a determination of response times, set-up times, and of the actual lifting that can safely be accomplished to provide a benefit. In critical cases, where the gate must opened and closed for project safety, an indentified, workable secondary hoisting mechanism may be worthwhile should there be a primary hoist failure. A secondary or back-up hoisting mechanism could be a secondary mobile or truck crane, an overhead bridge or gantry crane, or other hoisting mechanism.

3.8.4 Non-routine usage of hoist

When a hoist is used to operate gate(s) for a longer than normal times, the motor and or gearboxes may overheat and shut down. Similarly, those conditions could occur during extremely hot weather, or due to gate obstructions such as debris or expansive concrete, or to other materials such as bird nests that can affect the hoist machinery (see Section 3.7 and Chapter 5).

3.8.5 Dewatering

Chapters 2, 5, 6, and 7 discuss the installation of dewatering mechanisms for maintenance. From an operational consideration, it is important to understand how the removal of gate(s) from service can impact the project due to decreased discharge capacity. The number of gates out of service and/or time to return those gates to service must be determined. It is also important to understand how the operation of other gates can impact the dewatering, particularly the safety of working personnel. This item may include the needed time to remove personnel and equipment from dewatered areas.

3.9 Maintenance and inspections

Proper hoist operation includes regular maintenance. Maintenance can range from simple cleaning of hoists (i.e., removing insect and bird nests) and greasing of designated fittings, to complete overhauls and replacement of parts. Depending on the operator's experience and responsibilities, the ability to perform preventive maintenance will vary. Before gate operations gate components should be visually checked. The operator should look for potential or actual problems during operation. If equipment is operated beyond its load limits, damage can occur to a singular or multiple equipment components in the load path. When a problem is encountered, the operator must decide whether to discontinue the operation. This decision may require input from in-house or external support personnel. A regular log of both routine and major maintenance should be kept at the project (see Chapter 5). Both scheduled and unscheduled maintenance should be recorded, and the records should be maintained both on site and in the owner's designated file system. These records should also include a schedule and action plan for follow-up inspection, and maintenance and repair.

3.10 Emergency action plans

Although an Emergency Action Plan (EAP) typically focuses on dam failure, it may also need to consider problems related specifically to a gate failure. Gate failures can result in large uncontrolled reservoir releases and significant increased downstream flow. An EAP is an important dam safety document that covers all aspects of response to releases, uncontrolled or otherwise, that present a downstream danger. Since there are numerous sources of detailed information on Emergency Action Plans such as FEMA-64 "Federal Guidelines for Dam Safety: Emergency Action Planning for Dam Owners," this document does not include a detailed discussion of an EAP. However, a few gate-related issues that the EAP should consider include:

- *The response time for Owner and responding agencies, such as community emergency government*. This item is a function of the areas impacted, river travel time, and location. These items are often discussed at regularly scheduled dam failure exercises, such as those mandated by State or Federal agencies.

- *Appropriate action, if any, that the Owner can effect to reduce hazards or to shorten the notification time*. Such actions should be carefully considered and should not affect a determination to notify emergency management agencies. A warning notice that is cancelled is better than delaying warning until the gate or dam is failing or has failed.
- The conditions requiring activation of the EAP, which should be part of operator training as discussed in Section 3.12.

3.10.1 Response for gate failure

The four basic failure condition states for water control gates are:

- Failure to open
- Adverse gate closure
- Failure to close
- Adverse gate opening.

It is important that the owner determine the potential dam safety consequences for the four failure condition states. For the cases where negative consequences exist, it is important that the dam owner have a prepared plan for obtaining the necessary resources to accomplish emergency repairs and possibly also tentative strategies for addressing gate binding, gate removal, alternative lifting methods, etc. The owner may also want to have such a plan where the consequences solely affect the owner due to a loss of stored water.

3.10.1.1 Closed gate

When one or more water control gates cannot be opened a dam safety concern can result, especially when the reservoir is at a high pool level and water must be released to prevent potential dam overtopping. A gate that cannot open may also be a dam safety concern if the reservoir must be drawn down to reduce risk for another dam failure issue such as dam piping or sliding. If such conditions exist, local emergency preparedness authorities should be notified.

3.10.1.2 Open gate

If one or more gates cannot be closed, the most likely consequence is a loss of reservoir. The resulting outflow may also create flooding or other damages downstream. One of the most severe possibilities is erosion at the toe of the dam or of the spillway, which can lead to dam failure or loss of the spillway ogee.

3.11 Training

Training the Owner's staff in Dam safety is extremely important. The operators are often the most technically qualified persons on site on a frequent basis; they must be aware of potential failure mechanisms. The operator's training should include:

- A specified training program that includes both instruction and on-the-job learning (e.g., many union contracts provide for personnel apprenticeships at various levels before an individual may operate alone or as the lead).
- A written, current operation manual that specifically states when, how, and what to look for during operation. This should include a schedule for tasks to be completed on a routine basis (i.e., lubrication once a year and/or after each operation) and periodic inspections by others (see Chapters 4 and 7). (Note that a management supervisor generally signs off on changes to the operation manual.)
- An on-site meeting and training between management and operator whenever operation changes and as an annual refresher.
- Specific training with maintenance personnel to ensure that they understand the use of operation equipment. (Note that mapping the load path is a good practice to ensure that the operator understands the importance of each working component and any potential weak links.) Equipment operations and maintenance should be logged at the project and in central corporate records, as deemed appropriate.
- Participation in CSIRs, PFMAs, FTAs and other inspections (see Chapters 7 and 8).
- Annual training and/or meetings with other operators and management to discuss common practices, problems, and emergency actions.
- A list of personnel to contact in the event of a potential or actual operational problem.

Although formal and on-the-job training with experienced operator(s) is desirable, this is not always possible, particularly where part-time personnel operate gates. Regardless, even the part-time operator must have access to specific operation parameters to follow and a list of individual(s) to contact when problems arise.

3.12 Other

Specialized types of operations and events must be considered. The following sections describe a few operational considerations. These items may be part of the Water Control Plan or referenced in separate documents.

3.12.1 Security

Whether a project is manned or not, appropriate security procedures are critical. Besides a human presence, fences, locks, and cameras are the most common security tools. Depending on the risks and consequences, additional measures may be warranted. Terrorist threats are certainly a concern, but vandalism is more common. Standard security actions will be effective against most vandalism.

3.12.2 Conveyance systems

Conveyance systems, where water is directed from or to a dam by channels, pipes, and flumes often contain valves should be considered. These are not discussed here by specific type, but are mentioned only to bring this to the attention of the owner, since a conveyance system failure can impact the safety of a dam. For example, if a gate cannot close or is an integral part of the dam, such as deep gates, and the conveyance system fails, it could result in a partial failure of a dam and draining of the reservoir.

3.12.3 Pump storage

Operation of pump storage facilities may require frequent gate operation and may create unique conditions to be considered for safe operation. Ungated spillways at upper reservoirs have become common.

3.12.4 Seismic

Following an earthquake, the gate structure and the operating systems must be inspected before operation. Refer to Chapter 6, 7, and 9 for additional inspection and evaluation details.

4 Maintenance[1]

4.1 Maintenance manual

The gate and operating system manufacturer typically supplies a maintenance manual documenting the necessary maintenance activities for gates and operating systems. In many cases, especially for older gates and operating systems, this manual has become lost or was never available. In other cases, the manual may not have been updated to reflect modification and equipment replacement. In these circumstances, the manual (or update) should be prepared and made available to the maintenance personnel for reference. Consistent and thorough maintenance is very important to achieve proper long-term operation and asset life extension. Also, safety issues and procedures are documented in the maintenance manual.

Access to up-to-date historical records of maintenance, repair, and modifications can be quite useful for problem troubleshooting, by showing continuity of maintenance and providing a record of operational readiness. Historical records should be included in a maintenance manual or in a companion document. Where underlying issues remain unaddressed, some problems will tend to re-appear. These records allow identification of frequently reoccurring problems and documents how they were addressed. Replacement and major repairs of gate and operating system components should be documented in the historical records.

While the presence of experienced maintenance staff is advantageous, most gates and operating systems are likely to remain in service longer than the term of any individual's employment tenure. New or inexperience personnel are routinely called on to perform the required maintenance; therefore, the maintenance manual should be clear, concise, and understandable. Since the same maintenance personnel may not perform required maintenance from month to month, continuity and clarity is important in the maintenance manual and maintenance records.

A comprehensive, yet easy-to-understand maintenance manual ensures that maintenance instructions and checklists will be available when needed and

[1] Portions of this chapter were extracted or adapted from FEMA 145 (sect 4.2, 4.3).

they will be followed. Also, the maintenance manual should provide personnel with a reference to the hoisting or operating equipment for necessary maintenance work, should include a list of parts that require periodic replacement, and should include a list of required maintenance lubricants. After a major overhaul or component replacement, the list of parts that require periodic replacement should be updated. Typically a list (with location) of on-hand parts and on-hand lubricants should be included via hard copy or as part of an automated system. Maintaining an up-to-date list of supplies will aid procurement and ensure performance of on-site maintenance.

4.1.1 Typical operations and maintenance manual contents

There are several acceptable formats for an operations and maintenance manual. What is important is that the manual be well organized and readable so that information can be easily found when needed). An operations and maintenance manual often follows this organization:

- Introduction – Manufacturers Name, Contact Information and Warrantee. References to technical specifications are often provided here.
- Chapter 1 – General Description
- Chapter 2 – Installation Instructions (with Installation Diagrams with tolerances)
- Chapter 3 – Description of Gate and Hoist Operation and Criteria
- Chapter 4 – Mechanical, Electrical and Control Component Operations
- Chapter 5 – Maintenance (Includes Recommended Periodic Maintenance Schedule and detailed maintenance procedures. May also include maintenance history here or in a separate document.)
- Chapter 6 – Safety Issues
- Chapter 7 – Parts List (includes Recommended Spare Parts and Ordering Information)
- Chapter 8 – Drawings and Diagrams
- Appendices.

4.1.2 Maintenance processes

Many gate operations will follow an annual pattern. For example if the gate and operating system must function during a freshet, maintenance is scheduled during February or March. If there is a predominant wet season when the gates and operating systems must be in readiness, periodic maintenance should be scheduled approximately one month earlier. If the gates and operating systems must be kept at readiness throughout the year, then monthly or bi-monthly maintenance should adopted. If there is a seasonal predominance of trash or other floating debris, the removal schedule should reflect this. If gates and gate operating systems are required to be functional operate throughout winter conditions, often reliable gate operation may depend on continued operation of de-icing equipment and/or periodic manual removal of ice.

Gates and gate operating systems should be maintained at readiness, in other words, be ready to function when the need arises. To maintain readiness, a preventative maintenance approach is recommended and should become part of a manual and/or automated system for scheduling maintenance.

4.1.3 Maintenance systems

Manual maintenance systems remain common. Some facilities have adopted an automated maintenance system. Automated maintenance systems are encouraged and often include both a maintenance manual and a record (written or computerized) of the ongoing maintenance. As part of a more global maintenance approach, some owners have adopted a Reliability Centered Maintenance (RCM) or Root Cause Analysis (RCA) with the goal of identifying and programming safe levels of maintenance. Unfortunately, these maintenance approaches are not appropriate for many hydraulic gate and hoist applications. Hydraulic gates and hoists operations are often critical to dam and life safety, and must operate when needed. Hydraulic hoists and gates often will remain stationary for long periods of time, and by definition the hydraulic gate and hoist will have very short operation duty cycles. This leads to RCM and RCA determinations that routine maintenance should also be infrequent, which is contrary to reasonable dam safety behavior and standard of care. Because of the special safety significance of some gates and operators, special notations within the automated maintenance systems may be required to assure the necessary maintenance, and gate and operator, readiness.

4.1.4 Typical maintenance

Periodic adjustments, alignments, and lubrication are maintenance operations essential to long-term, reliable operation of gate parts such as wheels, rollers, seals, bushings, shafts, bearings, gear boxes, motors, and other moving components of gates and gate operating systems. Included is maintenance (scheduled and/or observed) such as replacing missing nuts or bolts; correction of misaligned components or causes of unusual noise; periodic lubrication; periodic removal of debris; and application of touch-up paint. All maintenance prolongs the asset life of equipment and overall operational readiness and availability.

The National Electric Code (NEC) changes periodically and it is necessary to verify that electrical and controls systems are compliant. Proper grounding is extremely important. Older designs may not include adequate grounding. Grounding may also deteriorate with time for a variety of reasons and should be periodically checked. The power cords can also deteriorate and should be periodically checked.

Many best practices for preventative maintenance are available from a variety of sources: industry, government agencies, the Internet, etc. Often best practices are cited by an inspector during a periodic detailed inspection. It is recommended that the maintenance manual be periodically reviewed and updated to capture and include selected best practices. Some best practices will be suggested in this chapter. Frequently, copies of periodic detailed inspection reports are included in an appendix to the operations and maintenance manual. The appendix also can contain information related to major maintenance and component replacements.

4.1.5 Periodic benchmarking

Periodic benchmarking can be used as a tool to gain consistency of practice concerning manual substance, form, and contents. Typically, benchmarking is a comparison of maintenance practices with other facilities, utilities, and companies that have similar gates and operating systems. Benchmarking is a process that allows an owner or regulator to periodically check what other owners have experienced in terms of operations and maintenance issues, and what other owners are doing in terms of equipment rehabilitation, and operations and maintenance processes and procedures. During benchmarking, one compares equipment and operation history, maintenance techniques and practices, and issues that have occurred with the gate and/or operating systems. Often manufacturers will identify where similar equipment has been installed. When a problem arises, chances are other owners may have experienced the same problem and may have already solved the problem, or may be willing to work jointly to achieve a solution. Periodic benchmarking allows sharing of knowledge related to common problems and what solutions (if any) were implemented.

Safety issues must always be a consideration when working near or on gates and operating systems. The hydro industry in particular is always adapting when a safety-related accident occurs or a safety concern is pointed out. Often a maintenance issue with a particular gate manufacturer and/or installation of a particular type gate will present itself at other installations. Benchmarking can help to highlight desired maintenance practices (not being performed) that should be performed, and techniques that need to be improved.

It is easier for personnel to understand a well-organized operations and maintenance manual presented in a common format that includes helpful pictures showing maintenance steps. Uniformity, thoroughness, and consistency (aided by periodic benchmarking) are key to maintenance success. Learning how others are doing the same maintenance work is always helpful, and may result in economic benefits as well.

4.2 Maintenance schedule

A schedule of routine maintenance activities should be documented in a permanent record. Hard copies should be filed for ready reference and use, but it may be preferable to maintain the schedule electronically within an automated maintenance system. Multiple available hard copies or availability via intranet or internet are also alternates. An available physical hard copy near gate equipment is always recommended.

Often routine maintenance is not documented. Even minor maintenance (such as a replacing a missing nut or bolt or performing a small realignment adjustment) should be noted in maintenance records. Often a small issue is a first sign of a larger issue to come. Today, many hydraulically operated gates are controlled remotely, and maintenance personnel may not actually see the gate operation during routine maintenance. The same maintenance worker may not be assigned when the next maintenance is scheduled. It is only through documenting of all maintenance issues that larger issue become apparent. Recurring issues should trigger scheduling of other inspection and maintenance activities.

Once a routine maintenance schedule is completed and being followed, the schedule should be periodically reviewed. For example, some scheduled maintenance may be delayed or not completely performed, which is quite normal. If this occurs, the delayed maintenance activity should be rescheduled. It is appropriate that the schedule be periodically checked for completeness and appropriateness. As structures age, maintenance requirements may change. Also, recurring problems may indicate the need to revise maintenance schedules and practices.

A schedule of routine maintenance activities should be documented in a permanent record. Hard copies should be filed for ready reference and use, but it may be preferable to develop and maintain the schedule electronically. A monthly report of maintenance activities performed and rescheduled non-performed maintenance activities should be maintained.

4.3 Routine maintenance

The most comprehensive method to verify the operation of gates is to operate them through their full range. Where this is impractical, more frequent operation, even if only through a small range of motion, is recommended. Because operating outlet gates under full reservoir pressure can result in large discharges, gate test-operation should be scheduled during periods of actual operation, or scheduled when some fluctuation in the downstream flows are permissible. If large releases are expected, outlets should be test-operated only after coordinating releases with water administration officials and notifying downstream residents and water users. When downstream impacts of full gate openings will result in adverse impacts, dewatering mechanisms such as stop logs or bulkheads are used. Even when these tests are done in the dry, they help verify any problems, such as binding, in the gate's full range of operation. See Chapter 8 for further discussion of gate exercising.

It is advisable to have maintenance personnel perform routine maintenance before gate test-operation is initiated. Maintenance personnel should be on hand or on call during gate test-operation activity. In the case of major equipment maintenance, operational checks and routine maintenance should always be performed before gate and operating systems are returned to operational status.

Sometimes gate operating personnel will respond during a plant inspection that they have never tried to open a gate, because they were not confident that the gate would close again. While this sometimes applies to spillway gates, it is more common with low level outlets. For a low-level gate that is designed to be permanently in place and never to be opened (such as a construction outlet), this is an acceptable response. However, the original design may have designated a gate for future emergency use that has been overlooked or forgotten (and remembered only when some future emergency need recurs). Submerged gates are the most difficult, expensive, and time consuming to routinely maintain. Often it is cheaper to abandon outlets than to maintain them. However, where these submerged gates are part of the operational plan for the dam, routine maintenance is necessary. Where a low level or submerged gate or other hydraulic gate is identified as no longer operational but is still a part of the integrity of the dam or water retaining structure, it should be inspected for water tightness and structural integrity.

4.3.1 Mechanical maintenance

4.3.1.1 General maintenance operational check

Maintenance usually involves periodic test-operation of a gate and hoist; this minimizes rust buildup in the operating mechanism and the consequent likelihood of seizure of parts within the operating mechanism. Corrosion such as rust is to be avoided, but realistically some does occur. Prior to or during this procedure, the maintenance personnel should first lubricate the various gate and hoist mechanical parts, particularly the hoisting mechanism including drive gears, bearings, and wear plates, while checking for adverse or excessive wear. Bolts, including anchor bolts, should be checked for tightness. It is not uncommon to find missing bolts and/or other components. Worn and corroded parts should be identified for replacement. When gate and hoist are operated, the manner in which the gate operates should be noted. Rough, noisy, or erratic movement could be signs of a developing problem. The cause of operational problems should be investigated for maintenance and corrected. If a gate has a manual operating system, how difficult is it to raise the gate. Does it bind? Does the gate move smoothly without jerking motion or side to side motion? Are there tearing sounds?

If a gate does not seal properly when closed, debris may be lodged under or around the gate leaf or frame or there may be damage to gate seals, gate leaf, or the gate guides. The gate should be raised at least 2 to 3 in. to flush the debris, and the operator should then attempt to reclose the gate. This procedure may be repeated until proper sealing is achieved or a maintenance issue is recognized. However, if the gate sealing problem remains, the gate should be dewatered, inspected, and maintenance completed (e.g., seals replaced, guides or sealing surfaces repaired, etc.).

In the case of a radial or circular style gates, twisting of the gate leaf structure can result in leakage along the seals as well. If this is the case, gate repair will likely be more complicated than normal maintenance and a gate engineer should be consulted.

4.3.1.2 Small manual operated gates

Generally small gates are of simple design with a manual operating system. The operating system mechanism may have a gear reduction system to reduce the amount of manual force required to raise and lower the gate leaf. Most manual hoisting mechanisms are designed to operate satisfactorily with a maximum force of 40 lb at the radius of the operating handle or handwheel. Excessive force should be neither needed nor applied to either raise or lower a gate. If excessive force seems to be needed, something may be binding in the mechanical system, or something may be jammed or wedged into the gate mechanism. The application of excessive force may result in increased binding of the gate and/or damage to the outlet works (gate leaf and/or frame). Maintenance should first include removing debris or other obstacles such as damaged seals, embedded metal, etc. If excessive resistance persists, the gate may be raised and worked up and down repeatedly in short strokes until binding ceases, and/or the cause of the binding becomes evident. Of course, a binding problem should be corrected to ensure continued gate operability. The metal used in gate seats is usually brass, stainless steel, bronze, or other rust-resistant alloys. Older or smaller gates may not be fitted with corrosion resistant seats, making them susceptible to rusting at the contact surfaces between the gate leaf and gate frame. Regular and periodic operation of gates with older type seals may help prevent excessive rust buildup and/or metal seizure. Eventually, maintenance will reach a point of diminishing return replacement may be preferable.

The gate and hoist components are often made from steel, which allows repairs to be done by welding and machining of the component. In some cases, the gears and components are of cast steel or other material that cannot be welded. Brazing is a possible maintenance repair, but likely will not be a permanent solution. In this case, the component should be brought to the machine shop and an estimate of repair made. In some cases, it is actually cheaper to purchase a whole new operating system rather than do extensive repairs.

For satisfactory operation, a gate stem system must be maintained in proper alignment with the gate and hoisting mechanism. Proper alignment and support is supplied by stem guides in sufficient number and spaced along the stem. Stem guides are brackets with bushings through which a stem passes. The guides prevent lateral movement of the stem and bending or buckling when a stem is subjected to compression as a gate is being closed. Stems can come out of alignment and the stems can be damaged by bending and buckling action.

The alignment of a stem system should be checked during routine maintenance. Alignment may be checked by sighting along the length of the stem, or more accurately by dropping a plumb line from a point near the top of the stem to the gate end. The stem system should be checked in both an upstream/downstream direction as well as in a lateral direction to ensure straightness. While checking alignment, gate stem guide anchors and adjusting bolts should be checked for tightness. A loose guide provides no support to the stem and could allow buckling of the stem at that point. In some cases, a guide stem may need to be strengthened.

If, during normal maintenance, the stem system appears out of alignment, the cause should be determined and repaired. The gate should be completely lowered and tension or compression taken off the stem. Misaligned stem guides should be loosened and allowed to move freely. The hoisting mechanism should then be operated to put tension on the stem, thereby straightening it, but the gate should not be opened. The affected guides should then be re-aligned and anchors tightened/fastened so that the stems pass exactly through the centers of the guide bushings.

If gate guides are damaged, replacement parts can be ordered from the original manufacture or an equivalent part obtained. Other options may be available from various manufacturers. In some cases, a damaged or corroded gate guide may be repaired.

4.3.1.3 Lubrication

A lubrication list should be maintained for each gate and hoist component at a project site requiring lubrication. For gates and hoists in particular, this lubrication list is commonly posted on an electrical or control panel. This minimizes the use of an incorrect lubricant. The list should include the lubricants to be used, a lubrication checklist and the frequency of lubrication required. The type of lubricant used and the date the machinery was lubricated should be printed on a weather proof tag and attached to the machinery component. The list should include the date of the last lubrication and the date for the next lubrication. If there is no such list, a lubrication specialist should be consulted.

Lubricants can include gear oil, bearing oil, chain lubricants, and grease. There are many different lubrication methods, including oil baths and grease fittings. Gate and hoists components include bearings, connection points, gearing, wire ropes, chains, and other rotating devices that require lubrication to operate smoothly without deterioration. Because gates and hoists do not run continuously, these components are often forgotten when it comes to lubrication. Incidents have occurred where gates and hoists have gone years without lubrication, resulting in a gate or hoist failure. Lubrication is essential to proper operation. Penetrating oils or other penetrating fluids which can break down the grease and harden seals, packing glands, and O-rings, should not be used.

A common cause of unusual wear is lack of lubrication or contaminated lubrication. The lubrication chambers and grease fittings can become encrusted with sand, dust, and dirt. Also they can become water contaminated. These components should be periodically cleaned to prevent the deleterious sand, dust, dirt, and water combining with the lubricant and contaminating the surface to be lubricated. Grit, metal filings, sand, and dirt can scratch a machine bearing surface. If not properly lubricated, corrosion can occur. Even Teflon® and other low friction bearing materials can be affected by grit, sand, and dirt, and these surfaces should also be periodically cleaned. Often old lubricant is not cleaned, oil filters are not replaced (if there was a filter), and sludge and old lubricants have not been removed. There are few maintenance manuals that suggest that dismantling and periodic cleaning is necessary. If lubricants are applied properly and scheduled as suggested by the manufacturer, dismantling and cleaning will be required infrequently. However, when contamination is observed, thorough cleaning is appropriate.

Gates and hoists are designed for use with various lubricants. Lubricant selection is an important consideration for the designer and the manufacturer, and the specified periodic lubrication is essential for long-term proper operation. Gate and hoist lubricants are generally simple, mild lubricants. The use of food grade lubricants is becoming increasingly common to reduce environmental contamination. As part of the installation, and operations and maintenance instructions, the hoist manufacturer usually specifies acceptable lubricants for a particular gate or hoist component. For older hoists, these lubricants may no longer be available. Equivalent lubricants can be determined by a lubrication engineer or lubricant supplier. Modern lubricants include penetrating oils and lubricants with many additives. If not maintained, Gate and hoist bearings may dry out during service. To remove dried or contaminated lubricants and allow introduction of new lubricant, some disassembly may be needed prior to greasing or installation of new lubricant. Often residues will collect within the annulus between the shaft or axle, and the bearing surface. A lubrication product that leaves a residual build-up is not recommended. If the service environment for the lubricant is to be submerged or partially submerged under water, then the lubricant must be water resistant and must protect the bearing surfaces but also provide the necessary oil surface to achieve the desired friction value. The lubricant also keeps dust, sand, dirt, and other contaminants from entering the journal and damaging the bearing surfaces. When the lubricant will be subject to prolonged periods at low temperatures and freeze and thaw conditions, special lubricants and more frequent lubrication is needed. Also, it is possible to over-lubricate. Packing glands and O-ring details can be damaged during lubrication, requiring examination and repair if damage is observed. Follow the manufacturer's instructions. If there is a lubrication packing gland or O-ring at the journals, take care to not displace the gland or O-ring. Glands and O-rings should not be visibly damaged. It is not uncommon to find that the packing gland and O-rings are damaged or have been completely displaced on older gates and hoists. Checking the drawings details, manufacturer's recommendations, and understanding the lubricant path and its function are recommended prior to lubrication.

It is recommended during maintenance that the lubricants be checked for proper level, water build-up, contamination, and lubricity. Lubricity is a measure of the lubricant's ability to continue providing lubrication. Tissue test of a lubrication sample can help the inspector determine if oil in the grease lubricant or if there is contamination due to metal filings in the lubricant. Take small samples of the lubricant from the bearing journal, bearings, grease boxes etc. and place them on a white tissue. Rub the tissue softly against the sample, flattening the sample. Oil should pass through the tissue and be exposed on the backside of the tissue. The flattened lubricant sample can be examined by a magnifying glass. The tissue sample should be compared with a sample taken from fresh lubricant. The acceptance criteria will be clear to the naked eye. If sand, or metal filings are observed in the flattened sample, the bearing or gear should be scheduled for closer inspection and maintenance. Lubricants should be fresh and not stiff. A putty knife is often used during maintenance to remove old grease and to check its consistency. Applying new lubricants during operation often will allow the lubricant to move within the journal or better distribute the lubricant to wearing surfaces. Of course this is not possible for all applications. After lubrication, often a reduction in hoisting noise is observed.

Lubricants are frequently upgraded and often additives, including penetrating oils, are included in the formulation. In many cases, the original maintenance instructions called for a particular brand name or type of oil or grease, and in some cases, especially with older equipment, these brand names are no longer available. Typically the original supplier of the lubricant should be contacted for a recommendation for a suitable replacement. Generally, older equipment has very simple, straightforward lubrication requirements.

Maintenance checks of journals, bearings, grease boxes etc. generally will find a fitting that has not been recently greased, or oil levels that are lower than required in the maintenance manual. Some gear boxes require gear motion to lubricate the gear surfaces. Gates with oil-filled stems (i.e., stems encased in a larger surrounding pipe) should be checked semiannually to ensure the proper oil level is maintained. If such mechanisms are neglected, water could enter the encasement pipe through the lower oil seal and cause failure of the upper and/or lower seals, which in turn could lead to the corrosion of both the gate stem and interior of the encasement pipe.

Problems with lubrication can often be identified during maintenance operations. Typically, it is obvious if grease will not enter a grease fitting. It is common for this to be caused by a clogged fitting or a crimped line. Water or other contamination can also often be identified visually.

It is recommended that hoists receive lubrication at least once a year and more often with more frequent use, such as after operation. Old lubricant should be drained, flushed by pumping new grease, or manually removed to allow new lubricant to appear. This will verify that fresh lubrication has been applied. Lubricant, which has been contaminated with water or other material, should be removed. The contaminated casing or journal should be cleaned and new lubricant installed.

Torque limiting operators require special grade lubricants and substitutions are not recommended. Verify with the manufacturer of that equipment as to the specific lubricant requirements.

When lubricating hoist machinery, the following maintenance actions are recommended:

- Check mounts for movement, loose locknuts, bolts, etc.
- Check for weld cracks and/or loose hardware
- Check gear case drain holes
- Check oil level of motor reducer and adjust as appropriate
- Check spur gear reducer oil level and adjust as appropriate
- Note any oil added or drained for comparison with future inspections
- Obtain primary gear reducer oil samples by:
    - Circulate the oil in the primary gearbox before taking the oil sample.
    - To properly obtain the sample, first determine whether the reducer has a sample port installed (often within the drain valve). If the sample port is installed, use the following procedure:
        - Connect a length of vacuum tube to the port
        - Using a vacuum pump and an extra sample jar, remove a third of the jar of oil to clear out the sample port and tube to ensure the sample is representative of the oil in the gearbox.
        - With a new, properly labeled sample jar, obtain a representative quantity of oil for testing.
    - If no sample port is installed, use the fill hole using the following procedure:
        - First clean around the fill hole port, which is normally located above the oil-full level.
        - Remove the plug, being careful to avoid introducing foreign material into the gearbox.
        - Introduce the sample tube into the gearbox and fill the sample jar with a sufficient amount of oil for inspections and testing.
    - The primary reducer gearbox oil sample should be sent to a lubrication engineering laboratory for analysis.
    - Check the oil level in the gearbox after obtaining the oil sample and top-off the gearbox as required.
- Lubricate all hoist bearings with fittings;
- Apply grease to the final reduction spur gears and inspect tooth condition – inspect the inside of the housing for any signs of rust, moisture, or discolored grease. Note any of these conditions and/or indications and, if

they exist, dry-out the gearbox and repair, refill as appropriate. Inspect gear faces for signs of undue wear, damage, and insufficient lubrication. Gear faces should be "tacky" with grease. Apply grease as may be required to the load-side faces of the gears and note the extent to which the gears may exhibit signs of damage/abrasion. During this operation, the hoist will need to be operated to obtain complete coverage of grease on the gear faces.

  - Inspect final reduction gear case invert for any signs of rust and/or moisture. Dry, clean, and repair seals as necessary.
  - Record as-found conditions and observations along with the amount and type of lubrication agents employed in the maintenance and inspection process for use in future comparison observations and continuity.

Most gate lifting tension members (i.e., chains, wire ropes) require periodic lubrication to reduce wear and/or corrosion. A cable should first be cleaned with a stiff wire brush dipped in solvent, compressed air, or steam and then lubricated immediately after cleaning. The manufacturer should be consulted for proper care recommendations, and the lubricant should be selected so that it will penetrate the chain/rope and provide a resilient exterior corrosion resistant coating without attracting dirt.

When lubricating chains, the following maintenance actions are recommended:

- Replace missing or damaged "keepers" on the gate chain
- Chain strippers and racks with damaged or loose hardware should be repaired
- Lubricate the chain pins and side plates
- While lubricating, number each cheek plate from top to bottom with paint stick as the gate is raised. The numbering is intended to facilitate identifying the links with required follow-up action during the lubrication and inspection process
- Grease chain fittings on the downstream side (slack side) of the sprocket as the gate is raised. Attempt to pump sufficient grease into the chain assembly so that it appears both between the cheek plates and between the inner cheek plates and roller
- Re-grease chain fittings on the downstream (slack side) of the sprocket as the gate is lowered. Attempt to pump sufficient grease into the assembly so that excess grease appears between the cheek plates and between the inner

cheek plates and the roller. Identify any links which appear to be seized (using the numbering system identified above) for follow-up actions
- If the chain contains stray current anode corrosion protection, check for any missing or significantly reduced anodes, grease link pins and cheek plates using a wire brush and glove taking care to not apply grease over the anode location. Replace anodes as appropriate.

For further discussion on lubricants and lubrication, see USACE EM 1110-2-1424, Lubricant and Hydraulic Fluids.

4.3.1.4 Radial gate trunnions

Trunnion bearings and anchorages are provided to transfer the gate load to the spillway structure. Trunnions should be inspected for excess friction. Keeper plates are usually provided to keep the pin from rotating. A keeper plate out of position or broken is an indication of increased friction and should be investigated as soon as possible. Radial gate trunnions will require greasing unless a self-lubricating bushing is used. Note that most gates rotate far less than 360 deg and thus friction loads are primarily applicable to only a part of the trunnions. Nonetheless, 360-deg greasing is important to minimize corrosion, which could freeze the pin. Greasing should occur, if gate has greasing ports, (Note: some gates, particularly older ones are designed without ports; however, it should be considered to add these if possible and operations indicate such) before operation, or according to manufacturer's recommendations. Automated grease lines may be used, but must be check periodically for proper operation since automated grease lines can become blocked and periodically contaminated. If not periodically flushed, lubricant in a long grease line can undergo years of aging from the time when grease enters and exits the line. Long grease lines should be avoided, if possible. A visual check and maintenance is always necessary before a critical gate operation. Access to trunnion locations can be difficult due to their location and safety concerns. Periodic visual check and verification of grease within the trunnion bearing is recommended. Without proper maintenance, trunnion friction can easily surpass the design criteria and lead to catastrophic gate failure.

4.3.1.5 Trash

Gate lifting and lowering can be affected by floating and submerged trash. Where gates have a downstream skinplate, the exposed structural beams supporting the skinplate can become loaded with trash and debris that interferes with gate operation. The gates may have an upstream plate to protect from trash. Trash can add to the gate lifting weight, can cause jamming or binding, and other issues that can be detrimental to hoist operation and gate integrity. Any build-up of trash that could affect gate operation should be cleared as needed.

4.3.1.6 Cleaning

Many gates have had rollers or wheel bearings replaced with sealed bearings. Once done, supervisors and maintenance personnel are left with the impression that no further maintenance is required, which could not be farther from the case. Grit, sand, and dirt will collect in the annuluses and on the bearing surfaces, and if not periodically cleaned will result in damage to the bearing surfaces. In some cases, bearings are sealed and care should be taken to avoid damaging the seals when cleaning. However, washing will allow you to tell if seals are damaged. This is also a good time to inspect the gate members. Use compressed air and/or a soft cloth to carefully clean the mechanisms.

Brakes can develop a residue buildup during braking operations and also can be contaminated by dirt and other debris. Use compressed air and/or a soft cloth to clean the surfaces. Do not use cleaning solvents unless recommended by the manufacturer.

Often a gate inspection is performed without cleaning the surfaces first such that maintenance requirements may not be visible. Few manuals specify cleaning, but this is a requirement that should be adopted as part of any normal maintenance program. During annual outside cleaning, the electrical and control components and sensitive mechanical components should be carefully protected when using power washing equipment. High pressure air or water or both is often used to remove marine growth, mussels, and other marine life that may have become anchored to a gate surface, seals or bearing surfaces, and to remove scale and loose paint. Often a long handled scraper is used during routine maintenance. Some gates cannot be raised or placed in a position that allows annual cleaning. In these circumstances, longer periods are often allowed between cleaning, so that cleaning can occur during outages or corresponding to the availability of stoplogs or other dewatering mechanisms. Original gate designs did not account for added weight of marine growth or marine life attached to the gate elements. Often the marine life will cause additional corrosion. Marine life on sealing surfaces can be a reason for leakage. Care is required when using high pressure air or water when cleaning as it can damage gate and operating components. This is also a concern if steam cleaning is used.

4.3.1.7 Alignment and adjustment

Alignment and/or adjustments of mechanical features should be made as necessary. Rough, noisy, or erratic movement could be the first signs of a developing problem. If alignment issues are observed, bearing or pillow block or other adjustments may be possible. Realignment or improved alignment can result in much smoother gate movement and hoist and gate operations. In some cases, the center of gravity of the gate leaf was not properly established for hoisting, and this can result in misalignment. Maintenance adjustment can result is significant operational improvement.

Whether caused by alignment issues, missing or worn parts, or some other cause, identification of operating problems and scheduled maintenance will extend the life of the asset and assure operational readiness. Part of maintenance is to determine whether the repair or correction can be done on-site or requires off-site capabilities. In-place machining is possible, but can be expensive. The cause of operational problems should be investigated and corrected. During this process, mechanical parts of the hoisting mechanism (including drive gears, bearings, and wear plates) should be checked for adverse or excessive wear. Bolts, including anchor bolts, should be checked for tightness. Worn and corroded parts should be replaced. Mechanical and alignment adjustments should be made as needed.

Hoist brake mechanisms require special attention. Brake shoes, solenoids, drums, discs, etc., should be carefully inspected for wear. Hydraulic thruster type brakes require periodic oil changes. It is important to use the proper oil viscosity since thin oil will result in delayed brake operation.

4.3.1.8 Touch-up painting

Gates and hoists are often constructed of thick rolled steel, cast steel, forged steel or cast iron construction. However, there are also machined surfaces that are more environmentally sensitive. The surfaces do corrode and routine painting should be scheduled. If a gate is normally submerged, often it does not receive the inspection and maintenance of a gate that is either partially or fully visible.

4.3.1.9 Sealing surfaces

Stationary sealing surfaces are usually stainless steel or carbon steel. A rubber or synthetic music note or flap seal on the gate contacts the sealing surface. As the gate moves, the seal moves with the gate, sliding along the stationary sealing surface. Rubber or synthetic seals wear out and/or become damaged during normal operation. Also, seal materials will age over time and should be replaced as needed. If allowed to leak (depending on location and head), high-pressure water can damage adjacent concrete via erosion and cavitation. A good maintenance program allows for inspection and replacement of seals. Seals wear at different rates, and based on wear, seals should be appropriately scheduled for replacement. Occasionally, stationary stainless steel or carbon steel sealing surfaces must be periodically resurfaced or replaced, which is a major maintenance operation requiring an outside specialized contractor.

Many older outlet gates are equipped with wedges that hold the gate leaf tightly against wall and sill seats as the gate is closed, thus creating a tight seal. Through years of use, gate seats (which may be constructed of wood, steel, or rubber) may become worn or damaged, causing the gate to leak increasingly. If an outlet gate has a wedge system, leakage may be substantially reduced or eliminated by readjusting tightness of the wedges. Because adjustment of wedges is complicated, inexperienced maintenance personnel can cause extensive damage to an outlet gate. Improper adjustment could cause premature seating of the gate, possible scoring of gate seats, binding of the gate, gate vibration, uneven closing of the gate, or damage to wedges and gate guides. Thus, only experienced maintenance personnel should perform outlet gate wedge adjustments. If an experience maintenance person is not available, a gate supplier or manufacturer should be consulted to obtain names of people experienced in such work. It is not recommended that you attempt this adjustment without the aid of someone who has previously done this adjustment successfully.

4.3.1.10 De-icing equipment and fluids

Ice can exert great force on and cause significant damage to gate structures. Ice protection can be accomplished by various means during winter months. Winter operations may include: (1) lowering reservoir below the gate; (2) leaving outlet fully open; and (3) usage of a bubbler, heater, or other de-icing system.

De-icing equipment requires high maintenance due to the wear and tear associated with ice formation and its removal. Fluids circulated by the heat pump or hot water pump cause a higher rate of corrosion. High maintenance requirements are often related to keeping the de-icing equipment running as long as possible. Once the parts, tubes, and cables begin to wear and break, replacement of the entire unit may be more effective.

4.3.1.11 Maintenance work safety

Maintenance of gates and hoists requires safety devices to allow maintenance work near the water on both upstream and downstream sides of the gate. Safety harness, suitable safety ropes and restraints should to be considered at all locations, but especially where work is required beyond walkways with handrail protection.

In some cases, the gate trunnions are in extremely dangerous locations. It is recommended that a hazard analysis and safety procedure be prepared and available as part of the manual. Also, operation of the gates and hoists can be dangerous should binding occur or an unexpected condition be encountered. Solitary personnel working on gate systems are discouraged.

Personnel should be made fully aware of dangers to people that may be encountered upstream or downstream of a gate and/or hoist during maintenance work. It is recommended that the gate be "tagged" out of service at the gate controls to insure that gate operation does not occur during the maintenance.

4.3.2 Electrical maintenance

4.3.2.1 General

Electrical systems associated with gates and hoists are generally straightforward. The first component is the power supply. Generally, power supply originates from the local distribution system or from the auxiliary station power supply system. There is a step down transformer. Rarely there will be medium voltage switchgear depending on the rated horsepower, but will always be a motor starter for the rated voltage. Generally, there is a power supply, controls, and telecommunications cabinet (indoor or outdoor). There will be local power circuits through the use of a dedicated uninterruptible power supply system to energize lighting, instrumentation and recording equipment, telecommunication equipment, warning alarms, gate position indications, water level monitoring, convenience outlets, and other devices. Often, there is local and remote control. Power circuits are rarely at the same voltage as the hoist motor. In addition, there will be grounding for the hoist platform, electrical components, and hoist motor. If there is a building or other equipment nearby, the grounding system should also connect to the building and other nearby equipment. Generally, electrical and control maintenance work is provided by an electrician or an instrumentation technician.

It is important that an electrical system be well maintained. Maintenance should include a thorough check of electrical panels and a test of the system to ensure that all parts function properly. An electrical system should be free from moisture and dirt, and wiring should be checked for corrosion and mineral deposits. Verify the tightness of bolted connections by either a calibrated torque wrench or by a thermal imaging survey. Necessary repairs should be completed immediately, and records of the repair work should be maintained. In remote locations, there could be radio-controlled devices for instrumentation monitoring and gate operation.

Electrical components such as motors, control boxes, electrical panels may have small space heaters or warming light bulbs to reduce condensation. Maintenance typically includes adjustments and replacing the box heaters and light bulbs.

4.3.2.2 Emergency and standby generator supply

In many cases, there will be an emergency backup and standby power supply, such as a stationary diesel-engine driven generator set or provisions for connection to a portable engine-driven generator set. When portable generators are used, it is extremely important to verify the phase rotation of the generator by making sure that gate hoist motors operate in the correct direction. Maintenance of generators used for auxiliary emergency power must include changing oil, and checking batteries, antifreeze, fuel supply, etc. to ensure reliable start and run operations. The emergency generators should be started once a month and the fuel day tank should be kept full. The generators should also be tested at load, preferably when operating the gate hoists.

4.3.2.3 Hoist motors

Hoist motors are generally 3-phase industrial grade motors. The motors are either mounted to a concrete base or on the hoist frame. The motor mounting bolts should be checked for tightness and corrosion. Generally, there is some type of coupler that connects the motor to a power shaft or gear box. The coupler should be checked for integrity and shaft alignment. In some cases, the motor will be a gear motor. Maintenance issues with motor are typical and well documented, including lubrication, alignment, mounting bolts, power supply, frame heaters, or control-related issues, etc. The insulation resistance of motors should be checked periodically and recorded for trending. Motors should be kept clean to ensure adequate cooling. In some cases, some older motors may have bearings that require lubrication. Motors with sealed bearings require no periodic lubrication. The proper type of lubrication should always be used. Lubricant types should never be mixed indiscriminately. Mixing incompatible lubricants can result in poor lubrication and bearing failure. Motor couplings should be checked for lubrication, alignment, and bolt tightness.

4.3.2.4 Power supply, lightning protection, and surge protection

Periodically, during routine maintenance, the power supply should be checked. Often the distance from the power supply to gate hoists is relatively long, and power quality can be an issue. Compensation may be needed to assure the motor can operate within its nameplate specifications. The insulation resistance of the power supply, including circuit breakers, should be checked and recorded. Circuit breakers should also be checked for signs of excessive heating. Circuit breakers should be cycled periodically. Disconnect switches should be checked for free operation and cleanliness. An inspection of electrical surge suppression and lightning arrester systems should be performed. Failure of these items may go unnoticed as they are intended to fail to protect other equipment. Spare fuses should be stored in an accessible location on site.

4.3.2.5 Control systems

A control panel is generally located near gate and hoist machinery, at a central location. The control panel will contain a disconnect switch and fuses (or a circuit breaker), motor starters, overload protection, relays, and cabinet heaters when necessary. Maintenance normally includes cleaning the control panel, checking for contact corrosion (cleaning or replacing as necessary), and verifying operation of the disconnect switch, fuses, circuit breaker, and heater. Starters, overload sensors, relays, and other devices are normally confirmed by gate operator operational testing. Gate position feedback and other instrumentation should be verified for proper operation and calibration. Any existing lockout capability to assure that there are no unauthorized operations should be verified.

4.3.2.6 Visual monitoring and telecommunication systems

Cameras are becoming more common so that operation personnel at a remote control center can monitor a gate site and obtain visual confirmation of gate operations. Typically, telecommunications are available at each hoist so that maintenance personnel can be in contact with control room personnel during maintenance periods. Maintenance and adjustments of telecommunication equipment are generally done annually once the devices are properly mounted.

4.4 Non-routine maintenance

If routine inspection of the spillway and outlet works indicates the need for maintenance, work should be completed as soon as access can be gained. Postponement of maintenance could result in damage to the installation, significantly reduce the useful life of equipment, and result in more extensive and more costly repairs when finally done. Most importantly, failure to maintain a power outlet system can increase risk of dam failure.

Depending on the severity of the required maintenance, authorities may be notified and kept aware throughout the maintenance period. In some cases, the reservoir must be drawn down to enable repairs of gates and embedded metalwork.

4.5 Major repair actions

Problems identified during operation, inspection, and maintenance activities should be assessed for proper action. If a problem cannot be corrected as part of normal maintenance procedures, the need for more extensive repairs should be investigated. Often extensive repairs are undertaken in a planned manner is what is often referred to as “major maintenance.” If the repair is very large, a capital improvement project may be selected to implement the work. Major repair could include the replacement of a gate, hoist, or embedded metalwork.

4.6 Maintenance logs/records

A manual documenting necessary maintenance activities and a historic record of past maintenance and repair that has occurred on gates is important to ensure continuity of maintenance and operational readiness. This includes records of routine maintenance, non-routine maintenance, failed components, unusual events, etc. A comprehensive record ensures that historical information will be available when needed.

5 Inspection Overview and Preparation

5.1 Introduction

There is an almost infinite variety and configuration of water control gates in use. This manual only covers gates that are more commonly found in practice. Where a special gate or equipment is encountered, the inspectors may need to reference documents available from governmental organizations (Bureau of Reclamation, Corps of Engineers, FERC, etc.) or the original designer, manufacturer or fabricator to perform an adequate inspection.

Visual inspection, combined with functional test-operation of gates and mechanical operating equipment, is the most practical way to determine the overall actual condition of an existing gate. It is important that inspection activities be well documented using a checklist that includes problem areas Operational tests are a critical part of gate inspection and are considered in greater detail in Chapter 8. Items that are out-of-the-ordinary should be noted on the inspection forms. The documentation of an inspection, the findings, and corrective actions generated should be documented in accordance with procedures the gate owner has already established. The form of documentation is less important than having clear, retrievable, detailed documentation that can be reviewed in future evaluations to assess conditions and maintenance trends on the gate.

If there are dewatered areas during an inspection that would normally be under water, the dewatered areas should be observed first. By doing this, when the areas are re-watered, the inspector can note and correlate changes with observations noted when the gate was dewatered. Observation of areas that are normally submerged and are difficult to dewater, may require divers or remote video equipment.

A test-operation of a gate ideally consists of operating it through a complete cycle from fully closed to fully open to fully closed under full loading conditions. At a minimum, each gate should be tested by a lift from the sill annually. Alternatively, a bulkhead or stoplogs may be installed to perform the full open test operation in the dry. For details of testing, see Chapter 8. It is often advantageous to perform the gate test operations first to detect any potential operational problems. The main inspection requirement is that a gate operates smoothly and reliably. Potential problems with a gate can manifest themselves in jerky or rough operation, leakage, vibration, abnormal noises, or binding. Special care should be taken when opening gates that have not been used for a long period of time. The issues involved go beyond the scope of this document.

A certain amount of regular inspection and evaluation is required to ensure the operability and the structural performance of water control gate systems. A typical inspection should include the structural aspects and overall operational characteristics of a gate. The performance of operating machinery needs to be considered as part of the inspection program.

Typical gate inspections need to be performed for the following reasons:

- Maintain operability
- Safety concerns
- Federal and state requirements
- Insurance carrier inspection requirements
- Internal inspection procedures.

5.2 Gate and operating system inspections

The type and frequency of inspection used for a particular gate depends on the type of gate, the usage requirements of the gate, the hazard classification of the dam, regulatory requirements, and the consequences of gate failure or misoperation. An important aspect of an inspection program is developing a suitable baseline with which to compare future inspection observations. If available, the initial design, fabrication, and/or record drawings can be used as the baseline.

Another important consideration when developing an inspection program is the public perception if a gate failure (structural or operational) were to occur. Even if the failure of a single gate does not cause a downstream hazard, the public will develop the perception that dam safety is insufficient.

5.2.1 Types of gate and operating system inspections

Gate inspections can be categorized as being informal, intermediate, periodic, close-up, or unscheduled inspections. Gate test-operations testing may also be included as part of the evaluation. Each of these types of inspections is discussed below.

An informal inspection is generally performed by plant maintenance or site staff. The site personnel should be trained to recognize deficient conditions and should have an understanding of gate construction and operational details. Short courses can be developed to train site inspection personnel on what deficiencies to be aware of during an inspection.

The individual(s) who performs informal inspections should participate in intermediate and periodic inspections with an engineering staff. Site staff can be a valuable source of hands-on information during inspection and can be instructed on critical features of that particular gate.

The intermediate, periodic, unscheduled, and close-up inspections are usually performed by an engineering staff. The individual(s) performing the inspection should be a technically qualified person knowledgeable in the operability and maintenance of gates and operating systems.

The following sections describe types of inspection for gate and operating systems that could identify deficiencies requiring evaluation.

5.2.1.1 Informal inspection

The informal inspection is a general, non-specific look for deficient conditions that may have developed since the previous inspection. It is usually performed by the site or field personnel. This usually involves an inspection from the hoist deck or nearby available access ladders and platforms to identify obvious deficiencies and questionable or uncertain conditions. This type of inspection can be a part of an overall inspection that includes the various dam components.

A checklist can be used to document findings when performing the inspection. Appendix A includes an example of a typical monthly inspection checklist. An actual checklist may include other features at a facility to be looked at by the field staff. The inspection can include routine maintenance including operating system lubrication, trunnion lubrication, draining condensate from oil pans, and wire rope and chain lubrication, etc. documentation of this type of inspection, along with observations, may take the form of an e-mail or may be captured in a database.

5.2.1.2 Intermediate inspection

The intermediate inspection is normally a walkthrough inspection that looks for obvious deficiencies of the gate and operating system. There are many reasons for intermediate inspections including owner's requirements, safety requirements, FERC Part 12 inspection, and other applicable state and Federal guidelines and requirements. The focus of inspection would include any obvious deficiencies and operational difficulties that had developed since the last inspection.

An intermediate inspection might include gate operation and system electrical testing, but would not typically include close-up detailed inspections of structural and mechanical components. Chapter 6 includes additional information on the inspection of different gate types. A checklist can be used to document findings by when performing the inspection, which will ensure that critical features are inspected. Appendix A includes an example of a typical intermediate inspection checklist. An abbreviated engineering report with a photographic record is normally prepared on completion of an intermediate inspection.

An inspection procedure can be useful for inspections that are more difficult to perform. Using new or rotating personnel for an inspection can result in the loss of historical knowledge regarding what needs to be inspected for a particular gate or hoist machinery; therefore, it is good practice to have a standardized procedure for performing intermediate inspections. Some examples of Inspection and Testing Procedures can be found in Appendix B.

5.2.1.3 Periodic inspection

A periodic inspection includes more thorough observations of a gate, operating system, and existing documentation. There are many reasons for periodic inspections including owner's requirements, safety requirements, FERC Part 12 inspection, and other applicable state and Federal guidelines and requirements. A team composed of members of different disciplines (structural, mechanical, electrical, etc.) may be assembled to perform this type of inspection. The team should be aware of maintenance requirements identified in the previous inspections that were not done. These maintenance requirements can be completed during the periodic inspection or carried over to be completed at a later date. Items that may be included in a periodic inspection include operational testing, machinery inspection, and close-up detailed inspections of components. Chapter 6 includes further information on the inspection of different gate types. Chapter 7 describes the inspection and testing of the gate operating systems. Chapter 8 describes operational testing.

An engineering report with a photographic record is normally prepared on completion of a periodic inspection.

As discussed in Section 5.2.1.2, Intermediate Inspection, an inspection checklist and procedures can be very useful to insure a thorough inspection. Appendices A and B include examples of inspection and procedure checklists.

5.2.1.4 Close-up detailed inspection

The major structural components and operating systems of a gate should be visually inspected within a 2-ft distance, which is called a “close-up” detailed inspection in this document. A thorough cleaning precedes “close-up” detailed inspections. If inspected from greater distances, cracks and other small deformities may not be apparent. For example, for radial gates, close-up detailed inspections would be prudent due to potential problems with gate trunnions that could only be identified by close-up inspection. In situations where a gate cannot be raised up to the deck for inspection, such as a radial gate, then special techniques like rope access and special scaffolding may be used for access. Section 5.4, “Personnel safety“ includes further information on safely climbing on gates. Note that a gate should be water blasted if possible to remove dirt and debris before a close-up inspection.

If a gate and operating system is easily accessible, then close-up inspection may be routinely included with a periodic inspection. A close-up detailed inspection may not be performed as often on gates and operating systems that are more difficult to access. These types of inspection decisions would be affected by the criticality of the gate, the hazard classification of the dam, and the condition of the gate.

A good time to perform a close-up gate and operating system inspection is when a gate is being repainted, since sandblasting will allow the best possible visual identification of cracks and corrosion that may have been hidden by the coating. An engineering report with a photographic record is normally prepared on completion of a close-up detailed inspection.

As discussed in Section 5.2.1.2, "Intermediate inspection," an inspection checklist can be very useful to ensure a thorough inspection. Appendices A and B include examples of inspection and procedure checklists.

5.2.1.5 Unscheduled inspections

An unscheduled inspection may be required for unusual deficiency or problem that may develop between regularly scheduled inspections. The problem may be identified during an informal inspection by the site personnel or during actual operation of a gate and operating system. This type of inspection may require a specially trained person and special equipment. Depending on the severity of the deficiency, an engineering report may be required to document the situation.

5.2.1.6 Gate test operations

An important part of a gate and operating system inspection program is gate test-operation, especially for flood control and regulating gates. Regulating and flood control gates that are infrequently operated should be test-operated (bulkhead installed as necessary) through full-travel, no-load at least once every 5 to 10 years and moved through a smaller range at design load at least annually, if not more frequently. Regulating and flood control gates must be in a state of readiness to maintain project safety while regulating flow or during a high flow event. Chapter 8 provides detailed information on the gate testing program.

5.2.2 Inspection frequency and personnel guidelines for various gate types

The frequency of a gate inspection depends on the type of gate, usage requirements, hazard level of the facility, current condition of the gate, and impact of gate failure (structural or operational) on the downstream areas. The data in Table 5-1 list frequency and personnel guidelines for different gate functions. Note that the inspection frequencies are only a guideline and engineering judgment should always be used in determining an actual inspection frequency. For example, gates that are required for flood control or that are primary water retaining elements of a dam would usually merit more detailed and thorough inspections performed more frequently than would a dewatering bulkhead. Another factor to consider is the impact of not being able to open or close a gate at a dam with a small number of gates, which could significantly affect the project's ability to safely pass a flood.

The higher the hazard level of the dam, the more important it is that owners and operators consider factors such as the potential for downstream property damage, loss of life, and environmental damage when determining inspection frequencies. While the hazard level should be considered when determining the inspection frequency, but the potential for downstream damages from a low hazard dam could be significant and should not be overlooked.

Another factor that could affect the frequency of close-up detailed inspections would be how often a gate is operated. For example, regulating gates, which typically operate frequently, more commonly exhibit fatigue and operational damage.

Factors that affect the inspection frequency of various gates are often related to a gate's function. The following sections describe some of these considerations.

5.2.2.1 Regulating gates

Since regulating gates are typically used more often than other types of gates, the inspection frequency should be greater.

5.2.2.2 Flood control gates

Flood control gates are any gates that are needed to pass water during a flood event. This type of gate is critical since the gate must be functional when the flood event occurs. Factors that would affect the frequency of inspections would include the consequences of a gate structural failure or a non-operable gate.

An intermediate inspection can be performed every year. A periodic structural inspection would normally be performed at least every 5 years. Due to the critical usage requirements, operational testing should be performed more often. The frequency of gate testing depends on numerous factors described above.

5.2.2.3 Emergency closure gates

This type of gate is typically similar to regulating gates, since closure may be required under flow conditions and the gate may be the primary water-retaining element. If accessible, these types of gates should be given informal, intermediate, and periodic inspections.

Table 5-1. Frequency and personnel guidelines for gate inspections.

Gate Function	Informal	Intermediate (a), (b)	Periodic (a), (b)	Close-up Detailed	Special
Regulating, Flood Control, Emergency Closure:					
Frequency	Monthly (c)	Annually	Up to 5 Years	Up to 10 Years (d)	N/A
Personnel	Field Personnel	Qualified Inspector or Engineer	Qualified Inspector or Engineer	Qualified Inspector or Engineer	Qualified Inspector or Engineer
Maintenance/Dewatering:					
Frequency	N/A	If Needed	(e)	(e)	N/A
Personnel	N/A	Qualified Inspector or Engineer	Qualified Inspector or Engineer	Qualified Inspector or Engineer	Qualified Inspector or Engineer

(a) Intermediate and periodic inspections may satisfy Federal or state inspection requirements.

(b) These inspection types may include operational testing (see Chapter 8).

(c) Some gates are not accessible for a visual inspection on a monthly interval, except possibly for signs of gate leakage.

(d) Use engineering judgment when deciding on the frequency for close-up detailed inspections, depending on gate condition, age of gate, hazard level, type of gate, etc. The period may exceed 10 years if justified by a qualified engineer. See Section 5.2.2 for further clarification.

(e) Dewatering gates should be inspected before use.

5.2.2.4 Shutoff or dewatering gates

Shutoff or dewatering gates are typically used to dewater a structure at a scheduled interval. Since these gates are not normally used between dewaterings, informal or intermediate inspections would not be required. It is good practice to perform an inspection on a dewatering gate before using it for dewatering an area to be accessed by personnel.

5.2.2.5 Mechanical/electrical machinery inspection

Inspections should not only consider the structural aspects of a gate, but also the gate's operational characteristics. The machinery is an important component that should be included in a periodic inspection. Items to check include the condition of the machinery, voltage and resistance readings, and vibrations or unusual noises during the gate operation. See Chapter 7 for additional information on gate operating system inspections.

5.3 Pre-inspection preparation

This section describes sources of information, methodology, and various tools that may be useful in preparing for a gate inspection. Each of the five types of inspections will dictate the appropriate level of detail for the pre-inspection preparation and an appropriate inspection plan. A plan for an informal inspection by the operating personnel may be a simple pre-job checklist. A close-up detailed inspection warrants significantly more extensive preparation and planning. Appendix A includes a sample of checklists and Appendix B includes a sample of inspection procedures described in this section.

A complete comprehensive inspection plan that is tailored to the particular inspection will enable an effective and timely completion of the task. Adequate pre-inspection planning will include arrangements for access, clearances for inspection equipment, and for personnel to be available at the proper time to allow an efficient, well executed gate inspection. Flexibility of the plan is required to accommodate additional work that may be identified during inspection activities.

5.3.1 Inspection checklist

The following pre-inspection checklist summarizes the activities discussed in this chapter and provides an inventory of the significant items that should be addressed before commencing an inspection:

- Review safety issues
- Review the gate design documents
- Review manufacturer's operation and maintenance manual
- Review the construction history
- Review pre-commissioning inspection and start-up test reports
- Review the maintenance records
- Review previous inspection reports
- Review operational history and operating procedures
- Review the dewatering plan
- Establish inspection objectives
- Prepare the inspection plan
- Prepare an inspection schedule
- Identify tools and equipment
- Conduct a pre and post job debrief.

5.3.2 Information sources

Design documents, construction history, maintenance records, operating history, and previous inspection records provide valuable sources of information for preparing for an inspection. The extent of document review depends on the type of inspection and the experience of the inspector.

5.3.2.1 Original gate design documents

Original design documents are valuable inputs to establishing inspection criteria and plans. Availability of design drawings and design calculations will vary. Materials, member and weld sizes, allowable stresses, fabrication method, structural design, coatings, other corrosion protection, and design operating conditions (for example, spillway gates designed to open or close under flow conditions) should be available from the original design calculations and drawings. Possible operational problems and structural deficiencies may be due to poor design details or operational procedures inconsistent with the original design.

5.3.2.2 Construction history

Records compiled during gate installation may provide information on deviations from the original gate design. While revisions during construction may have been incorporated into the design drawings, such modifications are less frequently reflected in the original design calculations. Structural design criteria used in the preparation of the drawings and calculations may have been circumvented by modifications implemented during construction or in later repairs performed after the gate is in operation. Photographs taken during construction, site log books, and construction inspection data may provide additional information. The completed structure should be documented on record drawings.

5.3.2.3 Maintenance records

Maintenance records can provide insight to problems. Repeated maintenance of specific gate and operating system elements and records of component failures/replacements establish trends that may guide the objectives for gate inspections. For example, if the gate seals require repeated replacement, inspection objectives may include an investigation of the reasons for premature gate seal failures. Significant gate changes should be documented on record drawings.

5.3.2.4 Previous inspection reports

If available, obtain copies of prior inspection reports and review these reports for information that may provide a basis for the condition of the gate and ancillary equipment. This can provide another source of gate history, operating problems, maintenance trends, and the rate of deterioration of the gates and related equipment. If previous reports recommended specific repairs, the current inspection plan should review of how closely the recommendations were followed, including documentation of repairs, and the success of these recommendations in eliminating the problem.

5.3.2.5 Operational history

While the physical inspection of gates typically involves visual observations of actual members, it is important to also obtain operations history for the gates. This information can include, but is not limited to: maximum headwater elevation and history (both historical and recent), design sequence of gate operations, historical gate operations including flow, reservoir elevation, and dates of occurrence. This information is important to ensure that a gate's original design criteria are being met in actual practice. If design criteria are being violated, there may be adverse impacts on the gate components.

The level of detail of the operating records will vary among installations. Before an inspection is performed, available operating records and procedures for the installation should be reviewed to evaluate potential usefulness in preparing for the inspection. Also, discussions with operating personnel about the recent operational history are an invaluable source of information on gate operability.

It is very important that the operation personnel be fully trained in the proper operating procedures for routine operations and unusual operations during flood events. Also, operation personnel are possibly tasked with periodically inspecting, testing, and maintaining the gate operating system equipment.

5.3.3 Guideline for the preparation of an inspection plan

Before the start of an inspection, an inspection plan should be prepared that establishes the scope of the inspection, roles and responsibilities, equipment requirements, and timetable for the inspection. At one extreme, the plan for a simple informal inspection of a simple gate including unrestricted complete access and operation of the gate can be completed with minimal downstream problems may be a single-page checklist outlining the major elements of the inspection and responsibilities for completing the inspection. The completed checklist may serve as the only deliverable and provide adequate inspection documentation. On the other hand, a low-level high-head gate, buried in silt, on a large dam that has not been operated in 20 years may reflect the other extreme, require months of preparation and consume hundreds of work-hours just to develop a complete plan for a close-up detailed or special inspection. The level of detail put into the inspection plan should correspond to the complexity of the inspection, and personnel safety requirements, and degree of cost.

5.3.3.1 Benefits

An inspection plan benefits everyone involved. Personnel participating in the inspection will have advance notice of the schedule and responsibilities of individuals involved with the inspection. A good plan will avoid leaving expensive talent sitting idle waiting for access to the gate, or even worse, having to terminate inspection activities due to unavailable equipment or restricted access. A good plan can improve safety. The inspection plan should be reviewed by parties involved, including the owner and/or operation personnel of the facility where the inspection is to occur.

5.3.3.2 Appropriate planning

The simplest inspection plans are typically the monthly informal inspections, which likely consist of a checklist outlining the significant features that field personnel should regularly examine (see example in Appendix A). Since these informal inspections may be repeated monthly, the inspection plan or checklist can be formulated once and used each time the inspection is performed. Such a plan may be revised as necessary to accommodate specific issues as they arise.

Similarly, intermediate inspection plans can also be developed as a form or checklist. Previous plans can be reviewed for details to include in the current plan. Appendix A includes a sample intermediate inspection checklist.

As the inspection complexity increases, such as for to the periodic, close-up detailed, or special types of inspections, a specific plan should be prepared. Appendix A includes sample checklists for these three types of inspections. An inspection procedure can also be useful to ensure a thorough inspection. Appendix B includes some examples of inspection procedures. These more thorough types of inspections may require the formation of a team composed of members from different disciplines, the owner/operator, and representatives from outside regulatory agencies to address all aspects of the inspection. Also, consulting firms specializing in a particular technical area may be brought on board. Planning and schedule coordination become significant issues as additional personnel are included in the inspection.

It is recommended at the conclusion of an inspection, that lessons learned during the inspection and improvement to the inspection plan be documented in writing for use during future inspections.

If an inspection is part of the FERC Part 12 or state regulatory requirements, the significance of the deliverables warrants particular attention in the preparation of the schedule and the assignment of roles and responsibilities in the planning phase. Again, as the complexity and cost of the inspection increases, planning activities become more significant.

5.3.3.3 Prepare an inspection plan

Each inspection, regardless of how simple, should have a written pre-established plan defining the objectives of the inspection, the conditions necessary to perform the inspection, the tasks, the personnel responsible for each task, any contractors such as divers, non-destructive examination (NDE) specialists or constructors (scaffolding, rigging, etc.), and the schedule for every task. The responsibility for preparing the written document, as with all other aspects of the inspection, should be defined in the initial organizational phase. Each participant may contribute to the written plan or the person responsible for coordinating the inspection can prepare the document. The plan should be reviewed and revised as necessary by the inspection team and the owner/operator of the facility to ensure that the plan is consistent with both the objectives of the inspection and the safety policies of the facility.

5.3.3.4 Common elements for an inspection plan

The initial preparation of a gate inspection plan should include these elements:

- **Establish inspection objectives**. The objectives should clearly establish the direction for the inspection. Examples of objectives include structural integrity, extent of corrosion, condition of coatings, condition of operating systems, electrical system, controls, etc.
- **Review the gate design**. Determine the type of gate, installation, structural configuration, coatings, operating systems, electrical system, gate controls, etc. This information can be ascertained from drawings and design documents. Original system descriptions and equipment data books are invaluable, if they exist. These descriptions and data may be detailed, formal documents explaining the operation of the entire dam or powerhouse, including the gate to be inspected. Design drawings are also a good source of information.
- **Review the gate operating parameters**. The inspector needs to understand the purpose of the gate, its operation (hourly, daily, yearly), and if the gate was designed to operate as it is currently used. Review the operating procedures and discuss gate operation with the operators.
- **Review gate maintenance history**. Review the operations history and maintenance schedule to determine if the gate has been performing satisfactorily. What are the maintenance problems (i.e., seals, weld failures, operating systems, electrical, etc.)? The gate may have been installed 40 years ago and that was the last time the upstream side was inspected. The operating system may not have been moved in 40 years as well. Determine the condition of coatings and degree of corrosion. A review of the maintenance history will tell a good deal, either through records or the absence of records.

- **Review gate operating procedures**. All aspects of the gate operating procedures should be checked to see if procedures are in place and that plant staff is appropriately trained in the usage of these procedures. Procedures that may need review include:
    - Site access and security requirements
    - After hours on-call plan
    - Primary and backup communications plan
    - Gate operation responsibilities
    - Flood operation facility plan
    - Spillway and sluice discharge tables
    - Remote operation procedures
    - Emergency procedures for when communications with offsite authority are not possible
    - Load rejection procedure
    - Emergency action plan (EAP).
- **Review dewatering plan**. If a dewatering operation is required to inspect a gate, the owner/operator should provide the details for dewatering the gate before inspection. The inspection should consider the dewatering plan from safety, personnel resource, temporary equipment, and schedule perspectives. The dewatering plan should be reviewed as a part of pre-inspection activities. The lives of the inspection team depend on the integrity of stoplogs, bulkheads, or other appurtenances that provide capabilities to de-water a gate, so these gates should be inspected by an engineer before use.
- **Safety**. General safety assessment for activities necessary to inspect a gate structure and related equipment should be considered as a part of pre-inspection planning. A safety and hazard analysis, tag-out or lockout procedures, OSHA procedures for confined space entry, fall protection, waterway safety, rope access, and special considerations for the presence of hazardous materials should be considered as a part of pre-inspection planning. Pre and Post Job Debriefs are required to cover all safety issues related to these inspections. Specific safety issues pertaining to gate inspection are addressed in Section 5.4.

These elements can provide a substantial amount of information for the gate inspection plan and associated checklist. After the plan has been established for a specific gate, these sources remain valuable reference tools for future inspections.

5.3.3.5 Prepare an inspection schedule

The inspection schedule should clearly define the start and completion dates for the inspection, each task that can impact finishing the inspection on time, and when each task is scheduled. The time frame may be impacted by seasonal reservoir level, generation requirements, outage schedules, or an emergency where a failure has occurred.

The complexity of the inspection schedule is a function of the magnitude of the inspection. A plan for a simple inspection of an accessible gate that requires only a few hours of preparation may be nothing more than a meeting notice and agenda provided to the inspection participants far enough in advance to ensure their attendance. For a difficult inspection requiring a reservoir to be drawn down, installation and removal of stoplogs or bulkheads, installation of scaffolding, etc.; a critical path schedule with projected task durations, and schedule logic reflecting a major project may be warranted. Without a schedule, there is a likelihood that expensive manpower may stand around billing time and expenses, while waiting for equipment to be cleared to allow access to gates.

5.3.3.6 Tools and equipment

Before the inspection, the team should assemble tools and equipment necessary to support inspection activities, including personal protective equipment. Suggested tools generally useful during inspections are:

- Cell Phones and Emergency Phone Numbers.
- Personal Protective Equipment, see Sec tion 5.4.
- Gloves should be considered when inspecting bare metal elements of gates and gate structures due to sharp edges.
- Camera and/or Video Camera. A still or video camera is essential in recording inspection activities and documenting the inspection findings.
- Thermal Imaging Camera (Infrared type) to assist with checking Pumps, Motors, Valves, Bearings, Electrical Cabinets, etc.
- Permanent Markers. Markers are useful in taking measurements and for highlighting specific items in photographs or video recordings.
- Tape Measure, Mechanics Rule, and Calipers. A tape measure is essential for field measurements. A mechanics rule and calipers can be useful in measurement of machinery components, bolts, rods, etc.
- Flashlights. For dark locations.

- Paint Scraper. A paint scraper can be used to collect samples from surfaces and check coating adhesion.
- Coating Thickness Measurement Tool. An electronic or magnetic device used to measure the thickness of the existing coating.
- D-meter or Ultrasound Testing device. An electronic device used to measure the thickness of the existing steel.
- Pit Gage. Used for measuring the depth of pits that develops due to corrosion.
- Geologists' hammer. The "pick" end of the geologists' hammer is a useful tool for examining the integrity of concrete.
- Rubber Coated Hammer. A rubber coated hammer provides a cursory inspection tool for steel structural elements where damage to protective coatings must be avoided.
- Welder's Slag Hammer. This hammer is used for weld integrity checks and removal of slag.
- Schmidt Hammer. This concrete inspection "hammer" provides a convenient tool for determining the integrity of concrete. This device provides a field estimate of the compressive strength of concrete.
- Laser Level. A laser level can be employed to check for deformation in structural elements. This device is easier and more convenient than the conventional "piano wire" method.
- Binoculars. Binoculars are useful for visual inspections where access is restricted or scaffolding would be required for visual inspections.
- Plastic Bags. Zip-Lock plastic bags are convenient sample containers, film holders, pencil bags, etc.
- Spare batteries.

Additional specialized equipment for Non-Destructive Examinations (NDE) such as ultrasonic testing (UT), x-ray inspections, dye-penetrant inspections, etc. should be supplied by services providing trained personnel and equipment qualified to conduct NDE procedures.

5.4 Personnel safety

The following sections describe some of the steps inspection personnel may take to ensure safe working conditions when inspecting gate structures. The steps listed are not meant to be all inclusive and are given as examples only. A safety hazard analysis and detailed assessment should be conducted to list safety issues and safety concerns, and then address all of these potential safety issues and concerns. Many of the topics are critical to personnel safety and this text should not be relied on as a sole source. The use of an on-site expert to provide advice on safety issues is important.

There are numerous Federal, State, and local regulations governing workplace safety. The Occupational Health and Safety Administration (OSHA) is the primary authority governing workplace safety and health requirements. The health and safety administrative authority for the particular inspection site and specific state or local regulations that may govern the inspection activities should also be identified.

Each inspector and support personnel is ultimately responsible for their own personal safety including having proper personal protective equipment, appropriate clothing, and awareness of safety conditions.

5.4.1 Safety hazards analysis

A safety hazards analysis should include a review of the potential safety hazards at a site and all documentation related to a gate, the owner's safety manual, safety orders, and emergency plans. A checklist should be prepared specifically for the inspection that provides key information to all inspection personnel. Hazard analysis establishes guidelines to ensure the safety of all inspection personnel.

Hazard analysis should include the following emergency data:

- List of facility contacts for reporting accidents.
- Contacts for local hospitals and emergency services such as ambulances, paramedics, local fire departments, and rescue teams.
- Review the owner's safety manual that pertains to the gate inspection activities. Note specific requirements for lock-out/tag-out procedures, confined space entry permits, and entry into de-watered structures with flooding hazards.
- Review of the site working conditions and potential safety hazards. The owner's safety specialist may have insights to specific job hazards at the site.
- For more complicated inspections, a Job Hazards Analysis (JHA) may be required. This type of analysis will include a step by step process to be used during an inspection, along with safety hazards and mitigation plans for that activity. Description of the process and forms can be found on the OSHA website.

- All equipment and facilities including electrical breakers, disconnect switches, motor controls, operating systems, cranes, hoists, or any other equipment that poses a threat to the safety of personnel (should it operate during the inspection) must have clearance/safety tags placed before starting any inspection activities.
- Personnel entrances should be marked to help ensure everyone on-site is aware of an ongoing inspection and the need to coordinate equipment operation.
- The owner's established clearance procedures should be reviewed. It is preferable that inspectors also place their own locks on isolation points where local policy allows.
- Emergency call codes/horn warning for project (e.g., seven long blasts = evacuate)
- Identify safe staging or assembly area in the event of an emergency
- Rescue plan.

Additional hazards to consider are:

- When climbing on or inside a penstock or sloping tunnel to reach a gate, personnel should wear approved safety harnesses together with a secured safety line.
- Ensure that adequate lighting is provided for inspection activities. If battery lighting is selected, sufficient backup lamps should be included to allow safe egress. If alternating current lighting is used, it should be protected by a ground-fault-circuit-interrupter (GFCI). All electrical extension cords and apparatus used in a wet environment should be protected by a GFCI or an assured grounding program. Low voltage lighting should be considered in this environment.
- Wet or icy floors or inverts are unavoidable in many instances. Surfaces inside penstocks, tunnels, or gate structures may be very slippery. Wear appropriate boots and/or waders and proceed cautiously. Always work in teams.
- Use caution when inspecting equipment with a high-pressure leak. Complete a visual inspection from a distance. The leak may be indicative of an impending failure.
- OSHA confined space requirements should be followed. In a confined space where CO_x or H_2S may be present, it is advisable (and may be required) to use gas analyzer meter to detect these gases.
- When entering upstream of a sluice gate (inside a sluice tunnel), good safety practice would include placing a wooden timber in the gate guide

that would prevent accidental closure of the sluice gate with personnel upstream of the gate.

- If hazardous materials are present that pose a health or safety threat, review Material Safety Data Sheets (MSDS) for the facility. Determine if there are lead-based coatings on the gates or associated equipment. Determine if there is asbestos present in gaskets or insulation. Should the inspection require removal of asbestos insulation or piping or equipment gaskets, approved personnel will be required to abate the material.
- Wildlife (snakes, rodents, insects [including bees and wasps], spiders, etc.) and their excrements, which could be disease carrying.

5.4.2 Pre and Post Job Debrief

A Pre-Job Debrief meeting should be performed each day before starting the inspection to review the inspection plan, cover safety issues, review the schedule, and review individual responsibilities. In some cases, safety issues may become apparent during the actual work. Depending on the issue, the work may need to be suspended and only resumed once a safety issue is remedied. This debrief should include a review of the dewatering and safety plan (see Section 5.3.3.4). A Post Job Debrief should also be held at the end of the day to review safety issues or other problems that developed during the inspection.

5.4.3 Confined space

If there is a potential for “engulfing” inspection personnel in a gate structure, a penstock, or a tunnel, the space will likely require treatment as a “permit-required confined space” as per OSHA and State Requirements. Rules and regulations that govern confined space entry are provided in the Federal Register, Part II Department of Labor, 29 CAR Parts 1910. Part 1910.146, “Permit-Required Confined Spaces for General Industry: Final Rule.”

5.4.4 Lock-out/Tag-out procedure

The Occupational Safety and Health Administration (OSHA) require all employers to have a lock-out/tag-out procedure in place to protect personnel during maintenance or service of machines or equipment. A sample lockout procedure can be found on the web site sponsored by OSHA for 29 CFR, Part 1910, Subpart J–General Environmental Controls. Most powerhouses have equipment “clearance” procedures in place to preclude operation of equipment during maintenance activities.

5.4.5 Fall protection requirements

If inspection points expose personnel to falls of six feet or more, fall protection pre-planning should be performed. Where inspections require working along unguarded heights, body harnesses and lanyards should be used. Scaffolding and ladders should be used where possible. The presence of sloping and wet surfaces should also be considered.

5.4.6 Industrial rope access requirements

Any climbing or repelling necessary to access difficult to reach gates (i.e., radial gates) should be undertaken by personnel specifically trained in industrial rope access climbing techniques to provide close-up access to the gates. Organizations that are currently addressing these issues include the "Society of Professional Rope Access Techniques" (SPRAT, www.sprat.org) and Industrial Rope Access Trade Association (IRATA, www.irata.org), which can be contacted for further information. California OSHA has developed specific legislation for the rope access industry.

6 Visual Inspection of Structural Aspects of Gates

6.1 Introduction

This chapter covers structural inspections of gates. In addition to the gate leaf structure, this includes guides, wheels, tracks, bearing surfaces, trunnions, trunnion anchorages, services bridges, ladders, and equipment floors and buildings. The inspection of gate operating systems is covered in Chapter 7. The level or degree of examination should depend on the type of inspection being performed and the site conditions during the inspection. For any gate that cannot be raised or that is inaccessible for direct observations of critical members, it may be necessary to use divers or remote inspection equipment to make the necessary observations.

6.2 Typical items to be inspected for gates

Section 6.2 presents typical items to be inspected for most gates and should be consulted when preparing inspection plans. This section provides additional items to be inspected for specific types of gates. While this section provides general information on what items should be reviewed in an inspection of a gate, specific types of gates may have gate-specific items that need to be inspected in addition to the 'general' items applicable to all gates. These gate-specific guidelines are presented in Section 6.3, which also includes additional information regarding reinforced concrete, wood, and cast iron gate constructions.

Inspectors should develop their own site-specific inspection checklists before any gate inspection. The checklist should be sent to the gate owner to see if there are other items that need to be specifically reviewed in the inspection. Table 6-1 lists typical items to include in a gate inspection checklist. Appendix A includes a sample of checklists and Appendix B includes a sample of inspection procedures. There are a number of inspection elements that are common to nearly all gates. Structural members, connections (welds, bolts, rivets, etc.), skinplates, and pins, hinges, or lugs generally make up the major elements for virtually all steel gate designs.

Table 6-1. Checklist of typical items to review in gate inspections.

	Skinplate	Structural Components and Members	Structural Connections, Bolts, Rivets, Welds, Pins, Hinges, Lugs	Frames, Guides, Supports, Anchorages	Lubrication	Seals	Coatings
Members in accordance with design drawings	●	●	●	●		●	
Field modifications not on design drawings	●	●	●	●		●	
Debris accumulation		●		●			
Vegetation accumulation		●		●			
Excessive corrosion	●	●	●	●		●	●
Loss of member thickness	●	●	●	●		●	
Damage to members or item	●	●	●	●		●	●
Missing members or item		●	●	●		●	●
Drain holes	●	●		●			
Distortion of members	●	●		●		●	
Alkali aggregate reaction				●		●	
Equipment cycled during lubrication					●		
Lug connection to gate		●	●	●			

It is more likely that older gates have been repaired or modified in the course of their in-service life. These modifications may not be shown on design drawings/documents. It is important to verify by visual observations that the in situ members are of the same size as the members specified in the design documents and to identify any undocumented modifications.

Inspections should start with an overall observation of the gate. Look for accumulation of materials not intended to be on gate members such as water, debris, and/or vegetation that indicate a lack of proper drainage. Check for the condition of the coatings and the amount of corrosion present. Check for missing, distorted, or broken structural steel members and connections. Also, special consideration should be given to any gate and operating system where components are in the flow path of the water. In some types of gates, the stem may be in the flow path. Where a component is in the flow path, it should be inspected for damage from ice or floating debris.

Critical members/components that transmit concentrated reactions or loads, particularly if they are not structurally redundant, should receive extra care in their observations. Typical critical members include major girders, radial gate arm columns, trunnion supports and anchorages, and lifting attachment lugs. The following paragraphs discuss elements of gate inspections common to most gates.

6.2.1 Corrosion

If corrosion is left to occur unabated, it could lead to structural failure of the gate system. Table 6-1 lists typical parts of a gate that should be inspected for excessive corrosion. Locations with dissimilar metals in contact are susceptible to corrosion. In addition, coatings on all members should be inspected to determine the condition of the coating. The coating surface should be visually observed for any flaking, powdering, peeling, debonding, or other defects. Additionally, the surface should be visually observed for signs of pitting or corrosion, which could indicate that the integrity of the coating has been compromised. Coatings on key structural components of a gate and operating system need to be inspected and noted in greater detail than for non-structural components. Periodic water-blast cleaning of the gate structure and ensuring that drain holes remain open can extend the life of the coating system.

Cathodic protection is sometimes installed to mitigate corrosion in some environments. Where passive types of cathodic protection systems are used, the visual inspection should verify that sacrificial anodes are still present and there is still sufficient material present to perform the protective function. In some installations, zinc blocks have been added on the upstream side of the gate to prevent corrosion. If these items are shown on the design drawings, field inspection should verify their presence. In some cases, the anodes may have been painted over during past maintenance rendering them ineffective. Active cathodic protection systems are not commonly used on water control gates.

Section 7.6.8 provides further discussion of bearing corrosion. Section 7.6.10 further discusses wire rope and chain corrosion.

6.2.2 Aging

In some cases, metals can lose mechanical properties with age. Some metals have a characteristic to become more brittle with age. In particular, cast iron, cast steel, and some earlier common steels can become brittle and less ductile with age and more susceptible to damage from cracking or fatigue. When originally installed, bronze has an excellent friction factor but this can diminish with age. Metals can degrade with time and usage. These issues may require the assistance of a metallurgist.

6.2.3 Cavitation

One of the more common examples of deterioration observed on steel gates is cavitation. Cavitation occurs when a critical combination of the flow velocity and reduced pressure allows water to vaporize. Offsets or irregularities on a flow surface exposed to high velocities produces turbulence. The turbulence produces negative pressures that cause the water to vaporize and form bubbles. Increasing pressure causes the bubbles to collapse, creating shock waves. The typical location of cavitation bubbles to form is at the lower downstream corners of the gate leaf skinplate, or adjacent on the channel walls and/or floor downstream of the gate slots. Under high velocity flow, gate slot fillers are sometimes used to reduce flow induced cavitation.

6.2.4 Skinplate

Gate skinplates should be visually observed for areas that do not appear regular or uniform or where there are indentations, sags, or signs of misalignment. Note any pitting, corrosion, denting, or tears. Inspect areas susceptible to moisture retention such as contact surfaces between skinplate and stiffeners. The area in and approximately 3 ft above and below the water fluctuation zone should be carefully observed in inspections to detect corrosion.

Be aware if the skinplate is attached on the downstream side of structural members; connections between the skinplate and the structural member are in tension. Also, connection areas may be hidden from view, and more difficult to inspect. Careful inspection of the quality and current condition of the welds is warranted. If questionable, the significant structural welds should be inspected and non-destructively tested by a qualified inspector.

The “v” shaped area between the downstream bottom of the skin plate and the bottom seal plate is typically undrained, full of debris and water, and contributing to significant corrosion of the bottom of the vertical purlin/ribs and bottom seal bolts.

Locations where the hoisting elements (chains or wire ropes) attach to the skinplate should be inspected carefully to ensure the lifting lug is not broken and that welds or connectors attaching lifting lugs to the skinplate are in good condition. At the same time, the hardware fastening a chain or wire rope to a lifting lug should be inspected to ensure all hardware is present and in serviceable condition. It is important to observe areas where the hoist elements, such as chains or wire ropes, contact the skinplate, to ensure there is no abrasion of coatings or other degradation to the skinplate or the hoist chains or cables. In some designs, the skinplate is thickened or protected by a sacrificial plate where hoist elements contact it, to ensure there is no loss of skinplate thickness (and resulting loss of metal and integrity).

An inspection of spillway gates should include observations that focus on potential gate damage due to overtopping by water, debris, or ice. Because the upstream face of the skinplate is exposed to abrasion and impact it should be inspected for damage and deterioration such as dents, deformation, thinning, and pitting. Although skinplate strength is rarely a structural problem for existing gates, a damaged skinplate may induce serviceability defects such as leakage and interference.

Potential causes for spillway gate skinplate leakage that should be noted during an inspection are corrosion pitting, loose rivets or bolts (particularly at field connections), and damaged rubber seals (especially along the bottom edge). Leakage is generally not an indication of immediate structural inadequacy, but can cause long-term gate deterioration by accelerating corrosion. In cold winter environments, leakage can cause operability problems via ice accumulations that prevent gate movement. The downstream faces of exposed spillway gates are common areas of accelerated corrosion particularly in areas that retain moisture such as the upper web surfaces of horizontal beams and at stiffener plates. The narrow space between back-to-back channels and angles is another common area of accelerated corrosion.

6.2.5 Structural components and members

Because gate structural components transmit the hydrostatic forces from the skinplate to the structure, they should be uniform in appearance. Note any misalignment, distortions, wracking, buckling, warping, twisting, denting, or corrosion that would decrease member thickness in a substantial manner. Flaking or missing paint at an area of distortion may mean that the distortion occurred after the surface had been coated. In most cases, the gate members should be horizontally symmetrical (that is, there is no discernable difference between the members on the right side of the gate from those on the left side of the gate). Note that the members may not be symmetrical in the vertical direction (when comparing the upper and lower gate members). Hydrostatic pressure increases with depth and member sizes and/or spacing are usually changed to accommodate this different loading. Shim plates and stiffeners are not normally considered to be load-bearing members.

Inspect for gate structure damage such as cracked plates or welds, and loose, missing, or broken bolts or rivets. Deformations should be inspected closely for impacted versus load-induced deformation. Cracks may develop due to fatigue, overloading or stress corrosion. Fracture-critical members (any major structural element or component) are especially important. An American Welding Society (AWS) Certified Weld Inspector (CWI) should perform the weld and member inspections. Typically, cracks can only be seen close up, and often only when the coating is removed. The inspection may require scaffolding or rope climbing equipment for access. A good time to inspect the gates is during painting when the steel surfaces have been cleaned, but before the first coat of material is applied.

Locations where members have been bent or distorted are particularly susceptible to the onset of corrosion. Key areas to observe for corrosion include angle supports, rolled plates, or areas of misaligned during assembly. Corrosion is also particularly common where skip and stitch welds are present. Look for signs of corrosion at the junctions where different structural components of the gate and operating system join (e.g., skinplate to ribs, support members to main beams, etc.) If wide flange or "I" sections are used as ribs, these members need to be carefully inspected for corrosion that is likely to occur under a contacting flange welded at both edges.

Structural members can be damaged by overloading. During inspection, ask the operations personnel for dates and descriptions of all occurrences where debris has become caught under the gate leaf and of other conditions that may have affected operation. For example, overloading can occur due to flow-induced vibrations, debris caught under the bottom seal during gate closing, or excessive friction in gate trunnion bearings. Misalignment or expansive concrete can cause excessive friction between the gate and adjoining wall surfaces. The gate operating system will exert its full force if there is no overload protection to stop the operating system, which may result in excessive stresses in structural members.

The structural members should be carefully examined to ensure they are in straight alignment and none of the members is bowed, wracked, bent, or twisted. In some cases, unaided visual observations may not detect subtle changes in the sweep or camber of structural members. The straight alignment of end (side) frame members, such as radial gate arm columns, can be observed using a string line attached to blocks that are clamped to the ends of the members. The string should be drawn taut and offset measurements recorded between the string and the member at end points and along the member. Measurements should be analyzed for trends to determine if the members have a permanent deflection. Laser sighting equipment can also be used for this purpose.

The girders should be examined to ensure they are straight and not racked or twisted in their alignment. Stiffener plates should be examined to ensure that they are rigidly attached between the flanges of the girder and that there is no distortion or corrosion of the plates. Welds/connectors should be inspected to detect cracking or other signs of distress.

To prevent corrosion of horizontal girders, drain holes should be installed in webs, end frames, and bracing members. Inspection should determine that drain holes are present and are not clogged with dirt or debris. If drain holes are present in the members, but there are observable areas of standing water, this indicates that drainage is not occurring and that remedial measures are required (such as cleaning and/or enlarging drain holes). Drain holes should be drilled (smooth) and should not be flame cut with ragged edges.

6.2.6 Structural connections, bolts, rivets, welds, pins, hinges, lugs, and hooks

Structural connections should conform to design documents, be tight, and be undamaged. Corrosion reduces bolt thread throat thickness and load area. In the case of rivets, sufficient material must be present to ensure that members are still mechanically attached. Welds should not be cracked, undercut, or exhibit other structural welding defect. Inspections should focus on missing, broken, or loose parts, loss of protective coatings, corrosion and rusting, cavitation, cracking. Welded and riveted areas are prime areas for corrosion.

It is especially important to be aware of the possibility that incompatible/dissimilar metals or welding materials are present. Irregular welds may have inadequate coating that leads to corrosion. Also, areas such as joints, cracks, rivet holes, and gaskets should be observed for corrosion. The tightness of selected bolts can be confirmed with a torque wrench, and the general tightness of connection bolts can be assessed by striking with a hammer. A solid ringing sound is an indication of a tight bolt or rivet, while a duller thud sound is an indication of looseness.

Pins, hinges, and lifting lugs should be examined for corrosion that would hinder proper operation. Hinge connections should be free and move easily with no jerking or irregular action. Look for signs of abrasion or wear, which may indicate binding. Lugs should be inspected to ensure uniform attachment without irregularity, deformation, cracking, or damage. Pins, especially those that could come into contact with water or other agents, should be covered or protected to ensure lubrication is not lost and foreign materials are not introduced into annular pin areas. This includes trunnion bearings.

6.2.7 Frames, guides, supports, and anchorages

Frames and guides should be uniform, flush with the structure (if they are embedded), and should not exhibit signs of binding, rubbing, corrosion, pitting, or distress. Some gate guides may be arc segments cast integral to the concrete structure. Exposed surfaces should be uniform and free of kinks, bends, or other out-of-place characteristics. Cracked or deformed metal can often be found on slide gate guides.

Damage to gate frames often occurs when an attempt is made to close a gate while debris is lodged in the gate opening. This can result in bent gate guides and/or gate seats. In some cases, differential settlement in the main structure that houses the gate can damage the gate frame. Structural settlement may result in a warping and/or misalignment of the gate seat or guides attached to the embedded gate frame. Leakage around the gate frame may indicate structural settlement.

Look for severe scraping or abrasion marks, which would indicate alignment or binding problems with gate operation. Sometimes binding and misalignment problems with gates are caused by AAR, which causes concrete growth, narrowing of the gate opening, and pinching at the gate leaf.

It is important to inspect the areas at the downstream end of spillway piers and alongside faces of the piers themselves. The inspector should be looking for spalling, cracking, rusting, bulging, or other signs that the steel reinforcement is corroded or otherwise compromised. Telegraphing cracks may align with the anchorage.

Concrete anchorages for trunnions, and hinge and torque tube bearings have many different configurations. These can include concrete and post-tensioned concrete anchors. In some cases, there will be embedment of a steel beam or girder. Trunnion girders, anchor bolts, tie rods, etc. should be inspected periodically for corrosion or damage. This is especially important if concrete growth due to AAR is present. However, only exposed portions of anchor girders and/or bolts, tire rods, etc. can be observed. Cracks around concrete anchorages may indicate movement of the embedded anchorage. If found, further investigations may be warranted.

6.2.8 Lubrication

Gate items such as trunnions, rollers, and wheels need to be lubricated. Lubrication of gate operating components such as motors, gears, linkages, wire ropes, and chains is discussed in Chapter 7.

Assessment of adequate lubrication is a major aspect of inspection. If lubrication is inadequate, the gate may not function correctly or could fail. In many cases, gates are left in a particular position much of the time. This results in the lubricant being squeezed out from between the rotating part and the stationary part of a gate trunnion. This can result in a metal-on-metal condition. Inspections should be made for signs of dirty or degraded lubricant. Unusual sounds during operation may indicate inadequate lubrication.

During field inspection, the effectiveness of the lubrication system should be verified for non-self-lubricating bearings. For best distribution of lubricant, a bearing should be cycled through its range of motion. Where grease guns are used to force lubricant into the bearing, the inspector should have lubricant injected and verify that old or inadequate lubricant is replaced by new lubricant. In most cases this can be visually observed. It may be necessary to collect the old grease that is extruded for environmental or other reasons.

6.2.9 Seals

In performing gate inspections, the condition of the seals and the connection materials should be carefully observed. During the field inspection, the seals should be inspected to ensure they are intact, still flexible, not excessively deformed, not broken, torn, abraded, or have other conditions that would impair their design function, especially at joints and corners.

Seals can be either flexible (such as neoprene or rubber) or rigid (metal). Materials that are used for seals include rubber, wood, and steel. Seals should be observed for leakage under field conditions. Seals are designed to minimize leakage between the seal and/or sealing surface. Newly installed gates require some set-in time before leakage criteria is achieved. Water loss due to leakage may be acceptable in some cases, although further deterioration of the coating on the structural steel may occur.

In rigid seals, look for areas of erosion caused by water leaking past the sealing faces. On high-head gates, high velocity of leaking water containing particles can erode sealing surfaces. Flexible seals may be damaged when a gate is handled during routine maintenance, when debris has caught between the seal and sealing surface on the gate frame, or when the sealing surface is too close to the gate (causing the seal to be pinched or crushed). Flexible seals may be damaged when the gate is exercised in the dry, as a result of the softer seal material rubbing against a harder material. Debris particles caught between sealing surfaces can damage the seal. Damage to rigid seals is usually due to foreign materials being caught between the mating surfaces. Flexible seals should be pliable so as to allow deflection for contact with sealing surface, but still sufficiently rigid to prevent hydrostatic pressure from bending them out of shape or alignment. Sealing surfaces should be observed for signs of deterioration, sharp edges, undercutting, wear, or other condition that would prohibit a tight seal.

The method of attaching seals to gates should allow for field adjustment to sealing plates. Embedded sealing surfaces (typically installed in spillway pier walls) are often made of 18-8 or similar stainless steel to retard corrosion. These side seal plates provide a smooth surface for seal contact. During field inspection of gates, sealing surfaces should be inspected to ensure that they are smooth and in good shape. No abrasion marks or scrape marks should be evident. If such marks are present, they may be caused by seal clamp bars, clamp bolts, and/or gate skinplate rubbing against seal plates. Also, abrasion marks could be due to excessive flow-induced gate vibration. If this condition is suspected, it should be further investigated because flow-induced vibration can cause gate failure.

Sighting along the pier (looking either upstream or downstream), should be used to determine if a sealing surface appears to be bulging into the gate bay area. Such bulging can be caused by alkali-reactivity (AAR) in the concrete, which causes expansion, or it can be due to corrosion of embedded metalwork (wallplate anchors or reinforcing steel). If the seal rubbing plates are expanding toward the opening of the spillway gate, this can cause binding of the gate and improper functioning.

Occasionally, seals of a double stem construction will be present. Sealing is actuated and maintained by reservoir water pressure applied behind the seal bulb. Where a seal of this type is present, water passage ports for the seals must be kept free of corrosion and debris.

6.2.10 Air vents

Gates in conduits require adequate venting just downstream of the gate leaf to allow atmospheric air into the conduit to prevent development of high negative pressures in the flow. If the air vent is restricted or blocked, damage could occur to the gate or the downstream conduit could collapse. Check to determine if air vents are clear and free of obstruction. The air vents may need to be protected to prevent freezing.

Crest gates frequently have provisions to aerate the overflow nappe and reduce vacuum-induced vibration. Note if nappe breakers mounted on the top of a crest gate leaf have been damaged or removed by debris or ice. Inspect side abutments aeration vents to confirm that they are clear and free of any obstruction.

6.3 Inspection items specific to individual gate types

This section covers additional items to be inspected for specific types of gates.

6.3.1 Bulkhead/stoplog

A crane and lifting beam (or frame) are typically required to set or remove a bulkhead or stoplog. Both lifting beams and lifting frames provide added height during installation to prevent tilting in the slots. If a lifting frame becomes stuck, it may be impossible to either lift the frame or bulkhead. The height-to-width ratio of a lifting frame should be at least 0.60 to reduce the potential of gate racking.

A bulkhead or stoplog should be stored on blocks so that it will not become warped and/or its seals damaged. Inspect the seals and skinplate for deformation.

Normally, bulkheads/stoplogs can only be installed under no-flow conditions. Practice has shown that bulkheads can experience considerable leakage. Other problems with bulkheads include jamming in the slots, trash, silt accumulation in slots, and filling valve malfunctions.

There are occasions when reinforced concrete has been used as a bulkhead/stoplog. The inspection should include observations of cracks, staining, bulging (which can be indicative of reinforcement corrosion), and spalling. Spalling may have a number of causes, among which can include freeze-thaw, reactive aggregates, and chloride penetration. Also note the condition of metal elements on the bulkhead/stoplog.

6.3.2 Drum gate

Drum gates typically have seals around the gate perimeter to keep the reservoir water from leaking into the chamber beneath the gate and to keep the water in the chamber from leaking out so that the gate position can be controlled. Needle valves are often used in the chamber drains when automatic control is provided. These valves are susceptible to malfunction and will void automatic action.

The problems most often encountered with drum gates include drum chamber inlet/outlet blockage, broken hinges, corrosion at the waterline, binding between the gate and sealing surfaces, and vibration of the gates during overflow operation. The drum chamber inlet should be inspected for restriction or conditions that might lead to blockage. The interior of the drum chamber should also be inspected for the presence of silt or materials that could block the chamber outlet. Since drum gates are hollow buoyant vessels, internal leakage is usually removed through flexible hoses between the drum and external drains. Failure of skinplates or drain hoses will allow the interior of the gate to fill with water and allow the gate to sink to its fully opened position. If the drum intakes to the flexible drain hoses become plugged, leakage to the drum interior will result in drum lowering. Inspect for broken fitting or bushings on the drum hinges. Checks should be made for plugged, cracked, broken, or missing drain hoses.

Freezing temperatures and ice formation can cause problems with drum gates. Ice can damage concrete or hinge anchorage. Ice on gate seals can lock the gate down in one position. If a drum gate freezes in a raised position and the chamber below is drained, then when the ice thaws, the gate drum will fall and result in damage to the drum or the concrete of the drum chamber. Additionally, if there is a heavy silt load in the water used to operate the gate, silt can settle out, cake, harden, and prevent the gates from operating freely. Look for silt buildup around the drum chamber drain. Seals that keep reservoir water from leaking into the drum chamber and seals that keep water from leaking out of the drum chamber must be maintained. Check for cracked spring plates and deterioration of spring plate joint seal material. Inspect for spalled or deteriorated concrete indicating movement of hinge anchors.

6.3.3 Hinged crest gate

The most common problems associated with hinged crest gates are flap binding (making the gate inoperable), silting up, and corrosion and wear at hinge joints. Because crest gates rotate about a bottom hinge line, their proper operation requires that the rotating gate leaf maintains a close tolerance, but does not interfere with the stationary side sealing armature plates. Therefore, look for signs of interference between the gate leaf and the stationary armature seal plates such jerky gate movement and/or rubbing noise during operation, bent skinplate edges, torn rubber side seals, and rub marks and scratches on armature plates. If indications of interference are noted, look for potential causes including loose or worn hinge trunnions causing a gate to shift laterally, impact induced side member deformation, AAR growth of pier concrete, bulging armature plates due to freezing of trapped water, and unequal movement of operating system causing gate leaf warpage.

Another common hinged crest gate configuration is the torque tube type where the gate leaf is cantilevered from a rotating bottom tube. The bottom tube rotation is generally powered from hydraulic cylinders mounted in dry compartments in one or both of the side abutments. An important aspect of inspecting a torque tube crest gate is to confirm the condition of the unique load path.

The gate skinplate is typically supported by vertical stiffeners cantilevered from the bottom horizontal torque tube. Observations should focus on the connection of the vertical stiffeners to the bottom torque tube because this is an area of concentrated load. Because the torque tube transmits the torque necessary to rotate the gate, the field-welded tube joints should be carefully inspected for indication of distress and movement. Bolts should be visually inspected for corrosion. Some bolts may be temporarily removed and inspected, particularly if there is a reason to suspect substantial loss of shank cross section due to corrosion.

The alignment of intermediate torque tube support bearings should be observed. A common approach is to measure the offset from a tightened wire strung between the armature plates. Look for deterioration of the support pedestal anchor rods and embedment concrete. Bearing deterioration may be detected by changing gaps between torque tube and bushing bearing surfaces, particularly in different rotation positions.

If a torque tube is powered by hydraulic cylinders mounted at both ends of the torque tube, then measurements should be made to confirm that the cylinders are rotating the tube in unison and not imparting a differential twist.

6.3.4 Flashboards

Flashboards are typically installed in a spillway to capture additional storage after the flood season. They are typically installed and removed by hand. Some installations are designed to be tripped or to fail when the reservoir rises to a pre-determined level. Inspect for corrosion or defects that may cause a failure at a lower reservoir level than designed. Check past records, if available, to determine if the flashboards tripped at the design level. The system should be checked to ensure that no modifications have been made to prevent the flashboards from performing as designed. Also, check to see that there are clear written operation procedures.

Typical problems observed with flashboards are: dry rot of wooden boards and panels, corrosion of metal panels, hardware, binding of sealing surfaces and hinges.

6.3.5 Floating bulkhead (caisson)

Floating bulkheads should be examined for any trapped water inside, which may indicate a leak. If the bulkhead is being set in the water, observe for a lack of buoyancy. Also, check for bulging skinplates, which may indicate over pressurization of the internal tanks. Verify proper operation of valves used to operate caisson.

6.3.6 Inflatable gates

Either water or air can be used to inflate the gate bladder. Air has certain advantages over water in that air requires smaller pipes, it may be easier to install, it does not freeze in cold weather, and it would probably inflate or deflate more quickly. An additional drawback to using water is that the water quality inside of the bladder could deteriorate, and when released (to lower the gate), it would generate adverse water quality conditions. Solids in suspension can settle in the bladder. An air system does also have some drawbacks. An air inflated gate can more easily oscillate with over-topping flow if the top of the gate is not properly designed. Since an air actuated gate is less dense than a water-inflated one, a water inflated gate will be more stable.

Observe inflatable bladders for tears, rips, punctures, or other degradation of the flexible materials. Where air is used to inflate the bladder, open the drains (if provided) to see if water has entered the bladder as a result of looseness of the clamping system or skin perforations. Look at the base of flaps and seams for signs of delamination or leakage. Look for blocked inlet and outlet ports. Verify that anchorages are firmly affixed to both the bladder and the structure. If cycle times for air handling units are available, review these records. Frequent actuation of the air handling units (to keep the bladder inflated) may indicate a leak somewhere in the system with a corresponding loss of actuation pressure.

6.3.7 Radial (tainter) gates

Inspect the lifting pin that attaches lifting ropes or chain to the gate for corrosion and/or wear. The pin is susceptible to corrosion at the waterline. Check for adequate clearance between side edges of the skinplate and side wall seal plates.

The trunnion hub should be inspected to ensure that joints between the hub and the end radial arm columns are sound and that there are no broken or cracked welds. In many cases, there will be tie plates welded over junctions of these two members, which should also be inspected for structural distress. In some cases, there can be areas on the trunnion hub where water can collect, resulting in corrosion and degradation of the member.

The welds on the trunnion hinge assembly and the condition of the assembly itself should be inspected to ensure that they are sound and that there are no signs of distress. The connections between the trunnion hinge assembly and the trunnion anchor beam (if observable) should be inspected to ensure they are not corroded, cracked, or distressed. The concrete on the pier around the trunnion hinge should also be inspected for signs of spalling, cracking, or other indications of distress.

The trunnion pin assembly should be observed for signs of corrosion or extrusion of bushing materials. As part of the inspection process, the trunnion pin assembly should be observed to determine if there is a gap between the trunnion hub and the bearing housing. Such a gap can allow rainwater, spray, and water vapor to enter. This can lead to increased corrosion of the trunnion pin and increased trunnion friction loads that the hoist must overcome. For installations where the trunnion pin is a hollow member, the inspection should try to assess the state of corrosion and presence of water inside of the pin. Note that there may be cover plates that need to be removed to make this observation. Trunnion pin keeper plates should be observed for displacement. A keeper plate out of position indicates pin rotation, which is a sign of increased trunnion friction.

Since the trunnion anchorage is embedded in concrete, it is difficult to determine if anchorage has been compromised. Look for signs of movement, cracks, or degradations in the anchorage area. If found, instrumentation should be added to determine the cause and magnitude of the movements.

Inspections should include a careful assessment of the lubrication of the trunnions. Look for signs of insufficient, degraded or dirty lubricant. This is especially true if the lubrication is done from a bridge deck that is at some distance from the trunnions. Where lubricant is introduced from a deck elevation and is forced to travel through long lubrication lines to the trunnions, it is possible that lubricant can be in the lines for many years, if not for decades by the time it finally reaches the bearings. Aging as well as the length of lines can result in caking of lubricant and line obstructions or leaks. If long lubrication lines are present, consideration should be given to purging grease lines periodically or relocating and shortening the lines so that lubrication is done at or very near the trunnions. This may require the addition of ladders with appropriate safety lines to provide access to the trunnions.

Some radial gates also have side rollers to reduce seal friction, binding and damage. These may require lubrication and should roll freely.

The gate should be opened and closed full-travel during lubrication, if possible, to ensure that lubricant is best distributed through annual cavities of the trunnion bearings. Gate exercise is discussed further in Section 8.2.4.

6.3.8 Roller dam gate

The unique feature of roller dam gates is that they are cylindrical gates that travel up and down an inclined rack. The rack should be inspected to ensure no teeth are missing. The corresponding mating surface on the gate is a gear that travels on the rack. The teeth of the gear should be solid with no cracks in the teeth or in the gear. Carefully inspect the throat of the gear teeth as this is an area where cracking may appear. If the roller dam gate has a facing plate attached to the outer surface, inspect the connections of the faceplate to the roller. If it is possible to access the interior of the roller gate, inspect the supporting members and observe for any ponding of water. If drains are available, open these and check for the presence of water in the gate. Submersible gates (and possibly some non-submersible) will be designed to have downstream pool water inside to avoid buoyancy.

6.3.9 Wheel and roller mounted gates

The wheel and roller gate family includes wheel-mounted or fixed-wheel, caterpillar/coaster, ring seal, paradox, and stoney gates. The most common problems with wheel or roller mounted gates are the misalignment of wheels and tracks, seizing of the wheels from corrosion and debris, clogging of passages for pressure actuation of the seals, and cavitation damage downstream of the gate slots. The following sections discuss common types of wheel and roller gates.

6.3.9.1 Wheel-mounted gate

Check for misalignment of wheels and tracks. Inspect for seizing of the wheel assemblies caused by corrosion and debris, which may be indicated by scrub marks on the tracks or flattened spots on the wheels. Before reinstalling the gate in its slot, make sure that the wheels move freely. Free motion of the wheels is essential to ensure proper lubrication and gravity closure. Ensure that wheel trunnions are properly lubricated. If a lifting beam is used to lift and move the gate, look for signs of distress that may be caused by an overload. Inspect for cracks and deformations. Plugs or grease fittings should be removed from the wheel hubs to observe for water. Inspect the pin seals for hardness. Inspect for corrosion damage. Inspect the bottom of the gate for evidence of dropping. Inspect the lifting lugs and attachment bolts for damage.

6.3.9.2 Roller-mounted gate

Roller-mounted gates (alt. caterpillar, coaster, tractor, Broome) typically contain numerous small moving parts (counterweights, pulleys, yokes, etc.) in the roller trains, chains, or carriages that are vulnerable to seizing caused by corrosion and debris. Before reinstalling the gate in its slot, make sure that the roller trains, chains, or carriages move freely. Free motion of the track is essential to ensure gravity closure. Check for cracked, broken, deformed, or missing pins, rollers or links. Flattened rollers indicate roller seizure, resulting in sliding instead of rolling. Check for broken or deformed carriages. Inspect tracks for deformations, corrosion, damaged surfaces, missing or damaged bolts and clips, etc.

In some roller gates, the seals are double stem and the sealing mechanism is actuated by water pressure in the reservoir. In gates of this type, water passage ports for the seals must be kept free of corrosion and debris.

6.3.9.3 Paradox and ring seal gate

The paradox and ring seal gates are very similar in design and function and can follow the same basic inspection criteria. Both gate styles use roller trains much like Coaster gates and are always electrically operated. The principle difference between each is that the paradox gate uses downstream metal seats and the ring seal gate, upstream rubber seals. During inspection of a ring seal gate, examine the interior fluidway surfaces of the body for corrosion or cavitation areas, particularly at the top and bottom of the fluidway where a misaligned follower could be offset. Check for silt accumulation in the lower bonnet by opening the drains. On the upper bonnet, look for cracks in the bonnet cover or leaky flange gaskets where the cover joins the bonnet. Check for leakage at the screw stem packing. This is evidenced by oil leaking from upper packings and water from lower packings. On the leaf and follower, look for corrosion and cavitation damage, cracked or broken ribs, and loosened stem connections.

When the gate is in the open position, the circular opening in the follower must align very closely with the circular openings in the upstream and downstream body halves. Otherwise, an offset in the fluidway is produced that could cause damage from cavitation. While the Paradox Gate relies on precise alignment of metal to metal downstream seats, the ring seal gate relies on seal movement produced by water pressure applied to the back side of the seals. Both the metal to metal seats and water systems are vulnerable to clogging by corrosion, mineral deposits, and silt.

Where paradox gate and ring seal gate designs were once used, current designs use hydraulically operated ring follower gates.

6.3.9.4 Stoney gate

The stoney gate is similar to a tractor gates except that water load is taken by racks rollers that are attached neither to the gate nor to the embedded frame. As such, the items required for a tractor gate apply to this type of gate.

6.3.10 Vertical lift slide gate

The vertical lift gate has no cover over the gate leaf. The stem is submerged and extends to the top of the water body where the operating system is mounted to an independent machinery base. The stem is supported by bushed brackets that are mounted on the concrete head wall of the structure, spaced to prevent stem buckling. Inspect stem brackets for firm hardware connections, corrosion and hardware damage. Stems should be straight, and stem couplings should be tight. On the leaf, inspect for corrosion or damage, especially cavitation damage, along the leaf bottom. Look for cracked or broken ribs, loose stem connections, and damaged or badly worn sealing and guide surfaces. The gate seals and seats are forced together using wedges. Inspect the wedges for damage, missing hardware and misalignment. The stationary portions of the wedges, seals, and guides are mounted on the gate frame. The frame is bolted to a “thimble” embedded into the concrete head wall of the structure. Inspect the frame portions of the seals, guides and wedges for similar problems mentioned above. Inspect the frame attachment bolts for missing bolts, corrosion and damage.

These gates feature both metal-to-metal and resilient sealing arrangements. They can have excessive amounts of leakage depending on the age and condition of the sealing arrangement. Additionally, the areas downstream of offsets in the fluid passageway, especially low in the corners, must be inspected for cavitation damage.

The operating system must be designed to handle the hydraulic forces. Inspect for heavily corroded areas, cracked or broken ribs, loose stem connections, and damaged or severely worn seating surfaces.

In some cases, slide gates will be constructed of wood. The specific items that should be observed for these gates, in addition to the general inspection items, include the presence of soft materials, and excessive warping or deflection. For maximum service life, the wood should be kept either completely wet all the time or completely dry as much as possible. Cycles of wetting and drying will cause degradation of the wooden members. Also, note the condition of metal elements on the gate.

6.3.11 Bonneted gate

The gate bodies and bonneted bodies should be inspected for corrosion and/or cavitation near the guide slots and on the floor just downstream from the sill. Verify that there are no damaged seats, loose or missing bolts, or clogged air vents. In the bonnet, look for cracks or leaky gaskets where the flange joins the bonnet bodies. Check for leakage at the piston stem packing (i.e., oil leaking from the upper packings, and water from the lower packings). On the leaf, inspect for corrosion or damage, especially cavitation damage along the leaf bottom. Look for cracked or broken ribs, loose stem connections, and damaged or badly worn seating surfaces.

6.3.12 Jet-flow gate

The jet-flow gate is very similar in external appearance to the bonneted slide gate having a bonnet, bonnet cover, and downstream body assemblies and hydraulic cylinder or actuator based operating system mounted atop the bonnet cover. Therefore, the inspection criteria identified above for the bonneted slide gate can also be used for the jet-flow gate. However, unlike a bonneted slide gate, a jet-flow gate has a bronze seal ring held in place with a stainless steel retainer ring mounted to the upstream gate body. Jet-flow gate inspection should include removal of the bronze seal ring by unbolting the stainless steel retainer ring holding it in place. If there is evidence of pitting or damage from debris, the bronze seal ring should be repaired or replaced to ensure the jet-flow Gate continues to discharge effectively. Although the design of the jet-flow Gate was intended to eliminate cavitation, the internal surfaces of the gate bodies should still be examined for evidence of cavitation as an indicator that the gate is not functioning correctly.

Early jet-flow gate designs incorporated a high-pressure lubrication system to lubricate the bronze seats mechanically fastened to the gate bodies. The lubrication lines should be checked to ensure they still deliver grease uniformly to the bronze seats. Later jet-flow gate designs use self-lubricating bronze for seat material making lubrication lines unnecessary.

6.3.13 Ring-follower gate

Because the ring-follower gate has metal-to-metal seals and seats, care must be exercised during the manufacturing process and while embedding the gate in concrete to ensure that the seats are in a near-perfect plane. If not, the gate will leak. When the gate is in the open position, a circular opening in the follower must align very closely with circular openings in the upstream and downstream body halves. Otherwise an offset in the fluidway is produced that could cause cavitation damage. Cavitation is often seen on the top and bottom of the frame.

6.3.14 Sluice gate

Occasionally gates will be made out of cast iron. In addition to the general inspection items to observe, the following specific items should be examined: cracks, excessive pitting, and corrosion/erosion of seal sections. While excessive pitting is an element of concern, it must be recognized that castings tend to have a higher number of casting defects/imperfections than non-cast elements.

6.3.15 Other gate types

Because of the almost infinite variety of gates that are in existence in the industry, there will be some occasions when specialty or less-common-type gates are encountered. Some typical examples of these types of gates include: (1) bear trap, (2) clamshell, (3) cylinder, (4) ring, (5) and fusegate.

Because of their relative rarity of occurrence, no detailed inspection items are listed for these gates. Rather, a custom-built inspection checklist, based on the elements common to all gates should be developed. This checklist would also include any items that are unique to the gate under observation.

7 Visual Inspection of Gate Operating Systems

7.1 Introduction

This chapter discusses the visual inspection of gate operating systems. As outlined in Chapter 2 the gate operating system includes: hoisting equipment and supports; lifting chains, wire ropes, or rods; attachment devices to supporting structure and gate; power sources; and gate controls. Gate operating systems, motors and controls must be in proper operating condition. Specific attention must be paid to components in the “load path” supporting a gate during operation. In addition to the attaching devices, load chains and/or wire ropes, drums, sprockets, sheaves, reducers, and couplings are critical for the operating system to function and support the gates during operation. These items must be considered as critical safety items and thoroughly inspected. Before proceeding with the field inspection of gate operating systems, the reader should be familiar with Chapter 5, which provides suggested intervals for performing gate inspections, and pre-inspection steps to undertake before performing an actual field inspection.

7.2 Common hoist components

There are too many different types and configurations of gate operating systems to cover every type. The following list includes the most common types of gate operating systems.

- wire rope
- chain
- rack and pinion
- screw stem
- hydraulic
- pneumatic
- water pressure
- bridge crane
- gantry crane
- monorail
- jib crane.

Appendix A contains sample inspection checklists developed for the most common type of gate operating systems. A customized form should be developed to ensure proper inspection of the features of a particular gate operating system. Once developed, the customized checklist may be used to improve inspection consistency and repeatability.

7.3 Visual inspection overview

Prior to performing a detailed visual inspection of gate operating system components, it is recommended the inspector mentally trace how the load is transferred from the gate through the operating system into its support structure. In other words, determine how the forces flow from the gate to the operating system; through the elements of the operating system such as the wire rope to the drum, the gear train, the motor, handwheel, or hand-chain to the support structure and foundation. If the operating system is gear driven, it will be powered by an electric, gas, or diesel motor. If the operating system is electric motor driven, it operates, from an off-site primary, electric power source, or from a backup power (gas-or diesel-engine-driven) generator set. As the motor turns, it moves the mechanical mechanism (drum, sprocket, spool, etc.) of the operating system to raise or lower the gate. If the operating system is hydraulic or pneumatic, a pump motor or compressor pressurizes a ram, and the pressurized fluid acts (extends or retracts a piston stem) to raise or lower the gate. The inspector should trace the load path through each component, understand how the operating system is intended to function, and identify the weakest operating element (and the frequency of use) as well as the weakest structural element.

Once the detailed physical visualization of the load path is completed, the inspector should understand the operation of the primary and back-up electrical systems as well as understand the control systems: remote, local, and other. If the back-up power system is a manual handwheel or a lever, it is necessary to understand how it works. The inspector must understand the use of limit switches and other devices used to govern gate travel. Use inspection checklists as a guide, and adapt inspection to the actual operating system configuration. There are many types of operating systems and many variations of these operating system types. Identically designed operating systems may have small variations. Do not take for granted that ostensibly identical operating systems are truly identical.

An inspector should become familiar with how the operating system loading changes as a gate is raised or lowered. As a gate lifts from its closed or an intermediate stopped position, there is a short time lapse during which the linkages, hydraulic piston, chain or wire rope, etc. begin to take additional loading until motion is developed (i.e., the gate breaks free and lifting is initiated). This loading is often called the “breakaway” force or “breakaway” load. This is the force that allows the gate to break free of static friction. The force incorporates adhesion between the gate seals and guides, bearing plates or pads, binding, pressure against the tracks, friction in the wheel or other bearings, and other resistance. Once the resistance and weight is overcome, gate movement begins. The breakaway force or load is often the largest load experienced during normal operation of the gate operating system. Understanding the operating system total load involves hydraulic, electrical, mechanical, and structural considerations. If a gate is fully submerged, the dead weight lifted is the buoyant weight of the gate leaf plus friction of seals, wheels, springs, and bearing blocks, etc., plus additional forces such as hydraulic down-pull. Also, there can be seasonal variations that result in higher gate breakaway loads such as ice, flood, debris, trash, silt, etc.

Lowering a gates is as important as raising it. Extreme care should be exercised during both operations. Special attention should be taken while the gate is moving up or down to make certain the hoist lowering mechanism and gate lower without binding or hanging up. For some hydraulic hoists, there is a cushion stroke and proper operation should be verified. Limit switches and position indicators should also operate properly. Gate motion should be observed from two or more vantage points with special attention paid to the making certain the gate leaf remains level during movement. As a gate lowers, the inspector should listen for any grinding or scraping noises that could be an indication of misalignment with tracks and/or guides. When the gate is in the down position, wire ropes and chains should not be loose and may need to be adjusted.

7.4 Support system inspection

Operating decks support fixed and traveling hoists. The decks typically are fixed at one end with the other end allowed to move for structural expansion and contraction. Typical problems are corrosion or failure of anchor bolts at the fixed end, inadequate clearance to allow for thermal movement, and twisting due to an unbalanced loading of the hoist structure or an issue with a support bearing.

Gate operating systems and hoisting machinery must be securely attached to a competent fixed structure. Typically, the operating systems are mounted on a bridge deck, spillway piers, a steel runway, steel or concrete platforms supported by the spillway piers, etc.

Operating systems attached to steel or reinforced concrete bridge decks require special inspections by a qualified technician. If a technician is performing the inspection, instances of metal loss due to corrosion and/or other damage to the deck structure must be reviewed by a qualified structural engineer. The assessment must determine if the bridge deck can safely support loadings imposed during raising or lowering the gates under the various credible load conditions. Additional (dead or live) loads on the structure including vehicular traffic, and ice/snow accumulations must be considered. A highway bridge deck across the dam should be inspected by a National Bridge Inspections Standards (NBIS) trained inspector or a licensed bridge engineer. The critical design load from the operating system often occurs when a gate is jammed in the gate slot and the operating system develops the hoist stall torque or breakaway force. The "breakdown force" is the operating system force developed by the hoist until the weakest element in the load path fails or the hoist motor reaches stall-torque conditions. It is most critical that the support structure never be the weakest element. Critical design loads can be mitigated by the use of load limiting devices such as a weigh system, load cell, mechanical load limiting device, or motor current limiter. Critical hoist loading is not normally encountered in practice, and many structural engineers may not be familiar with the condition. Careful consideration of all load factors is necessary. Operating system loads can be large for the breakdown load case. Care should be taken to understand breakdown loads, and how they apply to the bridge deck. Once the design is confirmed to be structurally adequate, a physical inspection of the bridge structure should be made to note deficiencies such as cracks, distortions of support members, corrosion, or loose connections. (For a more detailed explanation of bridge inspection, see: *Manual for Condition Evaluation of Bridges* [AASHTO 2003]).

If there has been a change in the operating system configuration, the revised loads should be determined and the supporting structure analyzed to ensure it has adequate design capacity and meets applicable structural and building codes. In some cases, the gate operating system is supported by a runway (rails), which allows movement of the operating system over multiple gate bays. Many older structural support systems have a simple support configuration where the operating system support framing spans from one spillway pier to the other. Understanding the support framing and how it transmits end reactions to the piers is important. It is important for inspectors to understand that loads from gate operating systems distribute to structural frames and slabs both across the spillway bay and parallel to spillway flow. As structures age, the end supports can become damaged due to a number of environmental factors unrelated to the operating systems. For example, if structural support is designed for a fixed end moment at points of pier supports and the end supports have become damaged, then the fixed end moment will not be developed at the beam to pier joint and the load carrying capacity of the support beam is compromised. Careful attention is required not only to structural members, but also to supports and connections.

7.4.1 Connections to dam, monorail, and hoist

The anchorage for fixed gate operating systems anchored to mass concrete structures consists of embedments, anchor bolts, threaded rods, or J-bars embedded in the concrete. The hoisting equipment is then secured using an appropriately torqued nut. The embedments, anchor bolts, threaded rods, or J-bars may be of a variety of configurations, steel materials and strengths. These can vary from mild to high-strength steels. The threads can be cut or rolled. The inspection of these supports should verify that the anchor bolts and nuts are present, undamaged and tightened per the original design requirements. Nuts frequently loosen and bolts become damaged. If shims are used and appear to be loose, the operating system anchorage may have loosened. In some cases the nut is not intended to be torqued to a value more than to secure the connection. In other cases higher strength bolted connections must comply with the ASTM A325, A490 or other codes. Concrete connections should comply with Appendix D of the ACI 318 code and post-tensioned connections should comply with the Post Tensioning Institute (PTI) Post Tensioning Manual and manufacturer requirements. Over-torquing or tightening can result in torsional bolt cracks that weaken the bolt connection. Over-torquing is not recommended.

In some cases, the actual operating system base has been anchored and then embedded in grout or concrete. Where concrete cracking is observed, it is necessary to determine if the cracking is superficial or may be the result of inadequate concrete reinforcement. Concrete cracking can be expected to occur along the embedded frame. Where cracking has been determined to be superficial, attention is needed to seal these cracks to prevent water-related and freeze thaw damage. Progressive concrete spalling can undermine the anchorages and embedments and exposed concrete reinforcing steel, and is cause for concern.

Moveable cranes and hoists have tracks or rails where the crane or hoist car traverses to position over a gate. The rails can be crane rail, railroad rails, I-beams, channels, or other metal shapes. Anchor bolts, rail clips, splice bars, and other plates (which secure the rails) must be present and firmly tightened. Attachment should not restrict movement for thermal expansion of the rail. Frequently, as the surrounding or supporting structure expands, settles, or adjusts, the runway rails will move out of alignment. It is not uncommon during an inspection to find rails no longer supported by the concrete deck or underlying concrete or steel beams. Rail clips may be missing or completely corroded away. Bolts can be sheared off or nuts missing. Rail ends may not properly butt and match one another. Rails may be laterally bent or twisted. Multiple wheeled cranes, hoist trolleys, and carriers have a specific separation distance between wheels. Some wheels have been designed to move (float) on their shafts to account for minor differences in rail spacing along the runway. If wheel spacing does not match rail spacing, binding and derailment may occur. If wheels do not properly engage rails when the hoist is under load, wheels may leave the rail surface and damage structural supports, operating system, and gate. Often the deck adjacent to runway rails is a thin concrete slab or grating, which is not designed for large concentrated loads, so the consequence of a derailment could be significant. Also, should derailment occur, personnel may be placed at risk, which is a significant safety issue. Runway rails need to be in proper alignment for the crane or hoist carrier to work properly.

7.4.1.1 Welded connections

All welded connections should conform to AWS standards and be visually checked for corrosion and fatigue cracks at regular intervals. Particular attention should be paid to steel immediately adjacent to welds in the heat affected zones. There is a wide variation of welded connections. Welds should be intact and defect free. Cracks in paint over welds may be an indication of a fatigue or stress crack. If a crack appears in the paint, the paint should be removed to permit a closer inspection of the weld. If a crack in a weld or near a weld is suspected, a more thorough visual and non-destructive inspection should be considered.

7.4.1.2 Bolted connections

Bolted connections should be visually inspected at regular intervals. One should look for elongation of bolts, missing bolt heads or nuts, loose bolts, loose shims, and spacing between objects located between the bolt head and the nut. Bolts should have a least two exposed threads beyond the nut. In some cases, distress of the bolted connection will include misalignment and bending of splice plates or cracks between bolt holes in splice plates or actual steel members. Where bolted connections have slotted holes, one member is intended to slide to allow initial adjustment of bolted parts, or to accommodate thermal changes. The bolt shank should be inspected to ensure that there is no significant wear, and that the thermal motion is occurring without distress.

7.4.1.3 Lagged connections

Lagged connections should be examined for proper seating of lag bolts and deterioration of the areas around lag bolt connections. The lag shank should be of full cross section and without visual signs of distress. Lag bolts can be hammer tapped during visual inspection to help verify the integrity of the embedment. Care should be taken to avoid damaging exposed threads.

7.4.2 Connection of operating system to gate

The connection of an operating system to a gate is critical since a connection failure will cause most types of gates to drop, may leave the gate inoperable and cause significant damage to the gate and surrounding structures. Gate connections must be maintained with structural integrity during raising and lowering. In addition, during the unusual circumstances when a gate jams or becomes restricted, connections must have a high safety factor and must not be permitted to fail.

Some connections between the gate and operating system have a mechanical function such as the ability to rotate and swivel, or the ability to equalize lifting rope or chain tension. The mechanical functions of the operating system connection to the gate must be visually inspected and design movement verified. Frequently, gate connections are underwater and cannot be visually inspected without the use of a diver or underwater camera. Unfortunately, gate connections may be prone to corrosion due to prolonged underwater exposure. In some designs, zinc is used to fill wire rope socket connections. If zinc is sacrificed (dissolved) due to cathodic action, the strength of socket connections may become compromised. Despite the difficulty, periodic visual inspection is important.

The operating system gate connection usually involves bolts, pins, and/or shackles connecting to lugs on the gates. This connection area of the gate also frequently has structural stiffeners. The operating system gate connection and any gate supporting structural elements must be free of cracks, distortion and corrosion. Pitting and loss of material due to corrosion must be recorded and incorporated into the structural analyses to determine its significance. Pin retainers and bolt nuts should be tight and not be distorted. Bolt clips, cotter pins and fastener rings have been used on some designs. These are a common location for dissimilar metal corrosion to occur due to the mixture of stainless steel and carbon steel pins, bolts, clevises, keeper plates, etc. and periodic replacement is required.

Wire rope connection sockets must be intact and wire rope free of damage and/or deterioration. Cable clamps must be field confirmed for tightness, and conform to type and number as required by gate design documentation. Evidence of cable clamp slippage should be repaired, and wire rope replacement should be considered when wire rope strength is reduced by any corroded, worn, abraded, or broken strands. If outer strands are damaged or frayed, wire rope should be identified for replacement. Chains frequently have a clevis connection or other pin connection of the last chain link to the gate. Chain links should be visually inspected for elongation, twisting, and reduced cross section. The pins and/or links can be damaged or experience loss of cross section due to chain link rubbing, wear, or corrosion, and periodic replacement is required.

Pins and bolts that rigidly connect hydraulic cylinders to gates experience load reversals and are susceptible to fatigue. They should be visually inspected for cracks, distortion, or slippage. There should be no binding or distortion that limits the intended connection movement. In some cases, this connection is a yoke arrangement that allows cylinder alignment to adjust as the gate is raised. The yoke assembly is often designed as a structural bearing permitting rotation. Lubrication records for lubricated bearings should be confirmed, and the grease fittings should be observed for signs of usage. Frequently, when hydraulic cylinders are replaced, lug connections on the gates are not replaced. Existing gate connections may not have adequate capacity for a replacement cylinder of greater load capacity, and analysis is needed and strengthening potentially required.

Inspection of normally submerged gate connections often requires the use of divers or an underwater camera. In some cases, stoplogs and/or bulkheads need to be installed for dewatering a gate. Gate to operating system connections may be inaccessible on some gates, and connection inspection can be performed only if the gate is withdrawn from the guide or slot. The gate removal procedure can be time consuming and expensive but it is important since this connection is critical and could result in catastrophic consequences. A simple annual operations test where the gate is raised and lowered may be insufficient to verify structural adequacy.

7.4.3 Hooks

One of the most critical parts on any operator is the attachment device to the gate. Failure of a hook or clevis is a catastrophic failure that results in “load drop” and may cause equipment damage, injury or loss of life. Therefore, careful attention should be paid to this item.

Hooks should be inspected for excessive corrosion, cracks, wear, and distortion. Hooks should not be painted. If a preservative is used on the hook, it should be removed to permit inspection. Surface corrosion should be removed with steel wool or a wire brush. Corrosion pitting must be sanded until the surface is smooth. Pitting that is too deep for manual removal by sanding should be non-destructively examined and the findings reviewed with the manufacturer and compared to allowable deviations.

The inspector should face the front of a hook (looking directly at it), the tip of the hook should be aligned with the centerline of the neck. A square with a leveling bubble may be used with the vertical surface placed in alignment with the center of the hook shank. If the tip of the hook is bent off center, it should be removed from service and non-destructively examined for cracks. The hook palm should be inspected for cracks, signs of over-stress, peening, and wear. Punch marks are usually provided by the manufacturer at points on the shank and the tip. Acceptable distance between punch points is usually provided in the maintenance manual. If the marks are not provided and the dimension is not given, it is highly recommended that punch marks be added to the hook tip and the shank and the dimension between the punch marks be measured and recorded for future inspections. The distance between the hook tip and shank should be measured during each inspection, and the addition of punch marks aid is taking an accurate measurement. If the dimension increases, it is a sign that the hook has been damaged and may be failing. If a hook is bent or distorted more than 10 deg (Per OSHA), it is recommended that the hook be replaced immediately. In the event there is any question regarding the integrity of the hook and its ability to safely hold the load, the hook should not be used and should be replaced immediately.

A swivel type hook should freely turn 360 deg with a full rated capacity load in place. The hook and its attachment into the sheave block should be defect free. The hook should be able to safely clasp the load. Hook sheaves and wire rope or chain should align and move properly even when the unloaded hook is on the floor for inspection. Hooks with less than a 2-ton rated capacity may be checked by the inspector manually by pushing up against the underside of the hook. Caution should be exercised so as not to create a slack cable or chain condition. The hook should sit securely in the rotation bearing without more than a 1/8-in. movement vertically, horizontally or diagonally. If excessive movement occurs, the bearing and/or bearing seat, hook nut, or trunnion is worn and should be inspected immediately.

The hook safety latch should be examined for distortion. The latch should be strong enough to keep a sling or load eye from coming off while the load is slack. The latch should be fully closed by the “close spring” without hesitation or assistance. Replace the spring if broken or weak. If the latch is missing, the addition of a safety latch is recommended.

When testing or using a wire rope sling, if a swivel hook experiences rapid turning while applying load, this is an indication of internal deterioration of the wire rope sling.

7.4.4 Joints, welds, stops, alignment

All joints, welds, and mechanical stops should be inspected for corrosion, pitting, or signs of distress. Welds for fracture-critical members should not be visually cracked, have excessive porosity, or exhibit any other structural defect (see AWS D14.1 Welding Code for inspection procedures).

Verify appropriate stops, limit switches, or other devices are in place to limit gate or hoist travel. Look for evidence of misalignment of metal frames or guides, and bent lugs or significant wear or torn water stops. Signs of surface rubbing, wear, and cracked welds or bolt connections or missing bolts should be noted for further evaluation. Jerking gate movement or excessive noise during raising and lowering may be signs of misalignment or binding.

7.4.5 Other

Operating systems are most frequently supported by steel or concrete beams. Beams are supported on columns or piers. Visually inspect columns and piers when inspecting the operating system. Water and freeze damage may occur at the top of the columns, piers, and expansion joints may become non-functional. Guides may be supported by the same columns and piers as the operating system.

Increased loadings due to alkali aggregate reactivity, soil, ice, thermal movement, and other dead and live loads can cause lateral deflection of the columns and piers resulting in misalignment and gate binding. Binding may not only be related to the binding of the gate within its guide. If binding occurs, consider other possible causes and conduct maintenance and additional inspection to eliminate binding.

The vertical lift gate center of gravity will change due to debris and ice loading. It also will change when gates are strengthened or replaced. For radial, hinged, and many other gate types, it can affect symmetrical or balanced lifting. After a gate modification, it should not be assumed that the operating system will function normally. The gate connection and the operating system should be checked and if necessary also modified. In gates that are designed to raise and lower under balanced upstream and downstream water pressure, downstream conduit or control valve leakage can prevent the gate from closing if the balanced hydrostatic loading is not achieved. Periodic visual inspection and maintenance or the downstream conduit and control valve may be required prior to raising or lowering the gate.

During inspection, it is recommended operational changes be discussed and recorded in writing. This documentation provides clues for solving future gate operating system problems.

7.5 Electrical and control inspections

Electrical and control inspections should be conducted in a logical, methodical manner. Typically, a hoist will have a power circuit, a back-up power circuit, and a variety of control circuits. Control circuits may vary depending on hoist operating requirements. It is recommended to obtain an electrical schematic diagram of the hoist control system before initiating an inspection. The schematic will provide the inspector with an understanding of the control function and circuit operation. For older hoists, schematic diagrams may not be available. In this case, it will be up to the hoist inspector to prepare a schematic sketch or diagram to document the power and control circuits from physical inspection of the panels, local controls, and equipment terminations. One analogy that helps an inspector when inspecting power circuits is that of a tree. The tree trunk is the power circuit (service entrance) and the tree branches are control circuits (feeders) to hoist control devices.

Where available, the portions of electrical and control component vendor manuals regarding inspection, testing, and maintenance should be referenced for information important to incorporate into an inspection plan for a site specific installation. Useful information on component testing can also be found in U.S. Bureau of Reclamation's (USBR) Facilities Instructions, Standards and Techniques (FIST) Manuals available at http://www.usbr.gov/power/data/fist_pub.html. In some cases these references can be adapted to document a gate hoist or operation system without instructions or manual.

Most electrical and control inspections are conducted while the operator is electrically energized. This always presents safety concerns. Many owners follow a strict set of procedures for conducting work near electrically energized equipment and systems. This includes a lock-out or tag-out procedure when a system or component is required to be de-energized for close inspection or testing. Applicable safety procedures and requirements should be followed.

The owner's O&M personnel should open all control, instrumentation, breaker, and electrical/control panel boards, switchboards, and device enclosures that are not pre-sealed by the manufacturer. Inspect the condition of the panel or enclosure, panel devices, and wire terminations. When originally installed, most panels or enclosures were equipped with a weather sealing strip or O-ring, which prevents rain, snow, dust, and other deleterious material from entering the box. Panels and/or enclosures may have several penetrations from conduits, cables, shafts, or other mechanical devices. These penetrations were likely sealed at the time of installation. Typically, knock-outs not used for the conduit or cable penetrations were left intact. Over time, the enclosure or door weather strips deteriorate, become damaged, or are removed. Vandals can remove panel knock-outs. Perhaps system modifications were made and previously removed knock-outs or drilled holes were not closed or sealed. In some cases, panel doors may not properly align to the face of the panel box, become damaged from use, or may be warped. Panels may attract nesting birds, animals, and insects. Nests often compromise the integrity of the electrical circuits and/or control devices, and can be a fire hazard. Compromise of the integrity of an electrical circuit and/or control device may cause/initiate erratic hoist behavior (raising or lowering) and may fault (prevent) required hoist operation. If nests or other animal, bird, or insect remnants are observed, they should be removed and access openings into the enclosure or panel should be blocked off. Vented enclosures should be checked for free air flow. Verify operation of cabinet heaters.

During enclosure or panel inspections, the inspector should observe wiring and wire terminations. Wire insulation should be intact except at the wire terminations. Wire insulation should be undamaged and show no signs of wire "hot" spots. Wire terminations should be mechanically solid. Wire nuts should be tight and checked with a wrench or torque wrench. For wiring terminations where vibration is present, wire nuts may loosen and if this condition persists an alternate wire termination may be needed. Control devices should be operable. Breakers and fuses should be of proper rating and functional.

7.5.1 Controls

Hoist controls may be basic or complicated. Controls may operate at the hoist location or remotely. Control operation at the hoist location is referred to as local control operation. Control operation at any location other than at the hoist location is referred to as remote operation.

7.5.1.1 Local and remote

Some control panels have a position switch or control that permits a hoist to be operated remotely or locally. Care should be taken to observe the position of the local/remote control switch when the panel is initially open. If it is required to have an operator present during gate operation, the local remote switch is often left in the local position. The inspector should be briefed on operating restrictions and observe that the control switches are set to meet the restrictions. Operating restrictions should always be in writing.

7.5.1.2 Load limit switches

The inspector should verify when load limit switches were last calibrated and whether calibration is in accordance with the limit switch manufacturer's instructions. Load limit switches sometimes are not routinely calibrated and will fall outside of the manufacturer's calibration specifications with time. Once outside of the calibration specification of the limit device, the load limit device cannot be relied upon and may create a false confidence which may result in dangerous operations. When operated within the manufacturer's specifications, load limit switches are quite reliable as safety devices. Under no circumstances should a load limit switch be load tested during normal hoist operations.

7.5.2 Motors

All motors are electrical/mechanical devices. Inspecting their mechanical aspects is further discussed in Section 7.7.6. Motors will either be AC or DC powered. Operating voltages should match motor nameplate data. The manufacturer's motor characteristics for voltage, amperage, and wattage should be stated on a visible motor nameplate. The inspector should record nameplate information from the motor. Often nameplates are difficult to read and solvent cleaning is required to make the nameplate readable. In some cases, the nameplates will not be legible and records will need to be researched to obtain motor characteristics. If the power source voltage, amperage, and wattage are inconsistent with the motor nameplate, the motor will not function as intended.

In some cases, the motors do not have continuous operation ratings and are only intended for intermittent duty. Hoists are designed to operate under most circumstances on an intermittent basis. The motor rating is often not as important as whether the motor runs smoothly throughout its duty cycle (opening and closing the gate).

The power connections to a motor should be observed. Wire insulation should be intact except at the wire termination. Wire insulation should be undamaged and show no signs of wire "hot" spots. Wire terminations should be mechanically solid. The motor armature should rotate smoothly without significant noise.

Inspectors often carry ampere meters and check motor phase amperage during starting and operation while the gate is being raised. These readings should be recorded for comparison to previous and future readings. In some cases, during the gate opening and closing cycle, motor amperage will increase. This may be a sign of increased gate friction, binding, or other load distress, and should be investigated further. In some cases, observed motor amperage may be above the nameplate amperage rating. Further investigation may be needed. Unusual amp-meter spot readiness should be supplemented with real time history monitoring to record voltage, amperage, and phase angle through an entire hoist duty cycle.

Since short circuits due to degradation of the motor's winding insulation is one of the most frequent problems experienced by aging motors, a motor inspection should include either the performance or review of records of the winding resistance testing. It is typical to inspect winding resistance annually and a reference for the insulation resistance (e.g., Meg-Ohm) tests for motors less than 500 HP is given in the USBR FIST Volume 3-4, Keeping Motor Windings Dry.

Infrared thermal scanning equipment is common. This is an excellent non-destructive instrument for an inspector to use during a hoist inspection. Thermal scans can provide excellent indications of motor bearing failure. Scanning should always be done during actual gate hoist operation throughout a complete open and close duty cycle. Before motor replacement, the amperage, voltage, and phase angle should be recorded before starting the motor and through the duty cycle until the motor stalls or stops. This time history motor-test-operation can explain a problem and may show a solution that does not require motor replacement and is often done as part of an engineering assessment. The motor power termination and wiring should also be thermally scanned as well as the motor housing. A hot spot on the motor housing is an indication that the motor insulation under that spot in the housing is deteriorating. If a hot spot is observed before hoist operation, the hoist should be thoroughly inspected and corrections implemented prior to operation. Monitoring of the hoist motor current and voltage can also assist in detecting or troubleshooting hoist system problems and gate binding. Older wiring, brakes, and motors may contain asbestos. This is difficult to identify in a hoist visual inspection. Further action that might disturb the asbestos should only be performed by qualified personnel.

7.5.3 Wiring and conduit

Wiring should be securely attached to termination points. Splices should be avoided. Insulation must be intact without cracks or exposed conductors. Taped lugs must be completely covered with appropriate thickness of insulating material. All conduits must be properly supported, grounded and securely anchored.

7.5.4 Normal power

The wiring for all power circuits should meet the requirements of the National Electric Code (NEC). Hoist motors can have horsepower ratings that vary from a fraction of a horsepower to hundreds of horsepower. The motor-branch-circuit wiring requirements vary depending on load, location, indoor or outdoor service, continuous versus other-duty service, motor type and manufacture, motor starter, and other factors.

Normal power characteristics of hoist motors vary. Normal wiring is rated at 120, 208, 240, or 480 volts. Motors are rated at 115, 200, 230, and 460 volts, but are designed to operate at voltages 6 to 10% above or below the rated voltage. For example, if you were to measure the voltage at the entrance to power wiring for a hoist system, you could measure 480 volts, but it is likely at the end of the power line to the motor, the measured voltage would be less, say 465 volts. For this reason, the motor nameplates always have a rated voltage less than the power system voltage. Where more than one hoist motor has been wired to a single power circuit, there is usually a sequence for starting individual motors that prevents multiple motors from starting simultaneously. Hoist motors typically develop high starting torque that requires inflow amperage to rise significantly for a short period of time. In some cases, motors are allowed to develop higher than the continuous duty amperage rating since the hoist motor is not operated continuously. Wiring and motor protection devices should be sized for the actual hoist(s) motor configuration.

7.5.5 Electric supply

All power side components including transformers, power transfer switches, circuit breakers, etc. should be inspected by a qualified electrician according to industry standard practice.

7.5.6 Power feeds

Stationary gate hoists are typically powered via wiring in conduit. There are various methods of distributing electrical power to movable gate hoists. The power feed for traveling hoists is a common source of operational failures, especially when the hoist machinery is installed outdoors and is used intermittently.

Systems for connecting power to the hoist include:

- Conduit
- Power cords
    - Tag lines
    - Festoon systems
    - Hinged track cable carriers
    - Cable reels
- Strung wire conductor systems
- Rigid conductor bar or angle systems.

In all situations described here, power should be turned OFF before beginning inspection because there is potential for contact with live wires carrying high voltage electrical current.

7.5.7 Power cords

Temporary power cords lain across the deck or pavement are subject to damage from two major sources. The first source is damage to the protective insulating jacket from abrasion and snags as it is towed behind the device. The second source of damage is abuse. In addition to damage, the power cords are subject to deterioration due to the normal aging process of the materials and exposure to the elements. Temporary power cables are often reeled or hand looped and stored to reduce damage. It becomes important to examine the condition of the outer insulation. Look for cuts, crushed areas, brittle cracks, and abrasions. Particular attention should be paid to the areas near both ends of the power cord. These areas are subject to constant radial flexing as the cord is towed behind the device. These two areas receive the most strain when the cord is snagged. Look for exposed conductors or areas where the cable insulation has been removed and the individual wire insulation is visible. Conductor cable ends need special attention. Particular attention should be paid to bend points.

The power cord connection to the power service should include a manual disconnect (preferable fused) in compliance with Article 610 of the NEC. Condition of exposed conductor wires and connection points must be closely examined for scorch marks and, loose contact with the tie-ins. Look for obstacles that can snag or cut the insulation. Listen for popping or straining noises.

7.5.7.1 Tag lines

Look for signs of wire fatigue including the appearance of stretch marks or elongation of the cable. The cable should be felt with the thumb and forefinger for thinning wires or breaks. The next items to be examined are the support wire or wire rope's brackets, tensioning devices such as a turnbuckle (if there is one), and the two points where the support wire or wire rope connects to the supporting structure should be inspected. Look for loose or corroding welds, and/or hardware. Immediately replace hardware and brackets weakened by metal loss from corrosion. Tighten loose fasteners. Grout around connections to concrete if necessary. The inspector should then check the condition of the support wire or wire rope should be inspected. The inspector should look for areas that are "thinned from stretching" and broken strands and excessive corrosion. Wire ropes with more than 5% of the stranded being broken should be replaced. The support cable should be inspected for excess sag. Listen for inappropriate squealing, grinding, or chattering. These occurrences will indicate damage of critical moving parts and should be more closely inspected and corrected as necessary.

7.5.7.2 Festoon systems

All procedures previously discussed about power cords should be followed. In addition, each of the track support points must be inspected. Look for loose or corroding welds, and/or hardware. Immediately replace hardware and brackets weakened by metal loss from corrosion. Tighten loose fasteners. Grout around connections to concrete if necessary. Look for loose or corroding welds, and/or hardware. Immediately replace hardware and brackets weakened by metal loss from corrosion. The track running surfaces where the trolley wheels contact should be checked for excessive corrosion and where. Track sections weakened by corrosion or wear should be replaced. Track splices should be checked for loose connections and corroding hardware.

7.5.7.3 Hinged track cable carriers

Since this is a power cord storing system, the power cord, along with other cables (if any) should be inspected and appropriate corrective steps taken as previously described. Special attention should be paid to inspecting the power cords' insulation jacket at the point where it has contact in the holes of the vertical plates. The hinges should be inspected for wear, damage, and proper lubrication. Broken, binding, or excessively worn hinges should be repaired immediately. The connections of the chain to the power service and the crane should be inspected and tightened or repaired as necessary.

7.5.7.4 Cable reels

All inspection and correction procedures should be performed to the power cord as previously described. The drum and flanges should be inspected with the power cord extended. Look for jagged or rough areas or holes that can abrade or cut the power cord. Check the cable for excessive tension or sag. If excessive tension occurs, the spring is too tight or the power cord is too long. Carefully inspect the spring. Look for excessive slack. Check the commutator rings and brushes. Look for burn marks and loose connections. Connections should be clean and tightened immediately. Blackened brushes and their connections should be dismantled, cleaned thoroughly until blackened areas are removed, reassembled, and tightened.

7.5.7.5 Strung wire conductor system

The conductor system should have a manual fused disconnect mounted and sized in accordance with Article 610 of the NEC. Circuit breakers may be used in lieu of fuses. Fuses and/or the circuit breakers should be checked for proper sizing. The fuse holders should be checked for corrosion or scorch marks. Inspect the condition of the wiring from the power disconnect to the ends of the conductor wires. Check the connection of the power leads to the conductor wires, remove blackened sections. Look for loose hardware and insulation damage. Tighten loose hardware. Replace hangers with broken insulation. Conductor should be taut and relatively level. If there is a cover over the conductors, inspect it closely. Look for tears or jagged edges. Trim damaged edges with side cutters. If a cover is torn and peeling away, it should be replaced. Tighten hardware as necessary. Inspect the collector mounting staff attached to the crane or trolley. Inspect the collector lead attachment to the crane or trolley's wiring. If there are scorch marks, disassemble, clean thoroughly and reassemble. Make certain pivot points they move freely. Make certain wheels rotate freely.

7.5.7.6 Rigid conductor bar or angle system

The conductor system should have a manual fused disconnect mounted and sized in accordance with Article 610 of the NEC. Circuit breakers may be used in lieu of fuses. The fuse holders should be checked for corrosion or scorch marks. Inspect the condition of the wiring from the power disconnect to the ends of the conductor wires. Check the connection of the power leads to the conductor bars. Inspect each hanger insulator. Look for loose hardware and break down in the insulation. If there is a cover over the conductors, inspect it closely. Look for tears or jagged edges. Trim these damaged edges with side cutters to make certain they do not catch on the collectors as they pass. If the cover is torn and peeling away, replace it completely. Make certain each splice is securely connected with minimal gap between the bars. Inspect the collector mounting staff attached to the crane or trolley. Make certain it is not damaged and holds the collectors in proper alignment with the conductors. Make certain mounting hardware is tight and/or welds are intact. Inspect the collector lead attachment to the crane or trolley's wiring. Tighten as necessary. Collectors should be examined in the same manner as for strung wire systems.

7.5.8 Auxiliary power

While a hoist is essential to safe and reliable gate operation, reliable back-up power is essential to reliable operation of the hoist and control system. For spillway gate hoists typically there is a back-up power source. Whether automated or manual, backup power systems should be test-operated periodically. Monthly operation of backup generators is common. In some cases, back-up power voltage measured at the hoist motor will be lower than the motor nameplate rating. This is not acceptable practice and may require modification of the back-up power system.

7.5.9 Power disconnects and protection

The National Electrical Code requires protection from short circuits and overloads for power cords and motors. Short Circuit protection may be a fuse or a circuit breaker. A fuse or a circuit breaker is rated in amperes and can interrupt the rated current at the rated voltage.

Motor circuits typically have a contactor with overloads or a relay to provide overcurrent protection. A motor contactor is typically rated in horsepower, and is capable of interrupting the maximum operating overload motor current at the rated voltage. In some cases, the inspector will encounter fused disconnect switches. The fuses provide the ability for the disconnect switch to open automatically in the event of an electrical overcurrent to protect the circuit feeding the motor.

When there is a reoccurring motor circuit trip, it is good practice to measure voltage, amperage, watts, and phase angle simultaneously, through a hoist duty cycle (gate raising and lowering cycle). Also, it is useful to make these measurements when a hoist is functioning normally, usually when first installed. On older hoists, these measurements can be taken at any time during hoist life. This information is very useful during troubleshooting when a problem does develop, and can assist the inspector in determining if a problem is mechanical or electrical related. These measurements when done periodically can also indicate some mechanical or electrical distress within a hoist mechanism or a change in the required lifting capacity due to an increase in friction or gate binding.

Typically, hoist motors have current overload, short-circuit and ground-fault protection built into their power circuits. Some hoist motors will have non-continuous-duty type overload protection. This is not a bad practice, but can result in nuisance tripping. The overload trip setting can be increased to reflect the required hoist motor amperage. Care should be taken to ensure that the nameplate maximum amperage is not exceeded. If the nameplate states only the continuous duty amperage, then contact the motor manufacturer to determine the non-continuous maximum motor amperage rating.

Other equipment and control devices will be required to operate from the hoist power service. These devices typically have a separate power circuit from the motor power circuit. Power ratings for these devices will be small relative to motor power requirements. However, these devices are essential to safe and reliable operation of a hoist. The inspector should examine these devices with the same diligence as the motor circuit. Devices should have some level of protection. Circuit breakers are the most common, but fuses also work.

The normal hoist power circuits can be constructed from armored jacketed cables, conduits, festoons, or open cable bus systems. The outside should be carefully visually inspected. Only thermal scanning techniques can tell if there is a hot spot within a jacketed cable or wiring within a conduit. Entrances into panels and switchboards should be clean and orderly to allow visual inspection of wires and components therein.

7.5.10 Grounding and lightning protection

All power supply and control components for operating systems must be grounded in accordance with the latest version of Articles 250 (Grounding) and 610 (Cranes and Hoists) of the NEC. The complete grounding system should be tested to make certain it will conduct to ground. The system must be checked from the operating system, through the power source and controls. The inspector should verify that the grounding is adequate to protect personnel from electrical shock. In areas of frequent lightning strikes, the power provided to the site may have lightning arrestors and surge suppressors. Degradation of these items may go unnoticed as they are intended to fail to protect other equipment. Therefore visual inspection of these items is recommended.

7.6 Mechanical inspection

Mechanical inspection should focus on moving elements of the gate operating system including drive train and bearings. Depending on a gate's operational mode (local, automatic, remote, etc.), size, and weight, the hoist may be manually or motor operated. A gate hoist operating system generally involves four components: lifting elements, hoisting machinery, controls, and power supply. These components need to be inspected, and are discussed in the following paragraphs.

In the case of a hydraulic or pneumatic hoist, the inspection should trace the movement of the fluid through the mechanical components of the schematic. When a gate has moving components such as trunnions, wheels, bearings, and seals, the mechanical inspection of these components should also be included. Inspection should be done when the components of a hoist drive train are stationary, and when operating. Drive train components may appear to fit properly together during static inspection, but during operation, they may demonstrate signs of wear, rotational imbalance, unequal gate raising or lowering, run-out, and other problems.

It is recommended that an inspector list and visually check each mechanical component and how one component fits another. If available, the fabrication detail drawings should be used to verify that surface wear does not indicate that replacement is necessary, but it could mean that adjustment is needed. Missing gear teeth, gear box and bearing noise, noticeable vibration, loose baseplates, misalignment, etc. are signs of distress. In hydraulic systems, fluid noise, unusual pressure rise or drop, discoloring of fluid, leakage, fluid contamination, and uneven movement of hydraulic cylinders, etc. are signs of distress. Pitting, corrosion or damage in the plated surface on piston stems will cause loss of performance and ultimate failure of the unit. An uneven surface on a piston stem can create leaks and damage seals. Particular attention should be paid to hydraulic fluid lines. Examination of fluid lines and supports is important to avoid failure due to excessive flexing and/or bursting under high pressure.

Careful documentation of wear, misalignment, and compound distress is necessary. In some cases, measurements may be needed to characterize wear and/or misalignment.

Simple observations are important. For example, a wheel gage may not match a rail gage; a worm gear may not be matched to the bull gear; a sprocket may not be matched to chain links, etc. Hydraulic oil pressures may not match with required design pressures. When doing a mechanical inspection, it is necessary to understand how components match and move relative to one another. Often an observed distress may be related to an adjacent component and not the component with the distress. Unequal wire rope or chain tension that results in uneven lifting or lowering could be related to wire rope or chain wear, or could be related to a slippage in a coupling.

Imagine when the hoist encounters a problem like a hydraulic line ruptures, or a wire rope or chain breaks. What would happen? Would the gate fall? Would the hoist remain intact? What are the ramifications? Would the operators be in danger? Would there be a spill of hydraulic fluid or lubricant? This is an excellent exercise to understand how a hoist system works. What happens as a hoist starts to raise or lower a gate? What happens when a hoist stops raising or lowering a gate? How does the hoist start and stop? What happens when there is a power failure as a gate is raising or lowering? With answers to these questions, an inspector will better understand the requirements, function, and control operations of a gate hoist.

7.6.1 Trolley wheels

With long-term use, a wheel can flatten or develop a concave groove. A sign of rail wear is the flattening at top of the rail head and peening of the head toward the edges. In both cases, a trolley can continue to function until the thickness of the wheel tread becomes structurally thin. Flattening at the top of a rail is of less concern. The wheel treads should be visually checked for cracking and peening over the edges. This occurs infrequently, but when observed, is significant and requires immediate evaluation and maintenance.

Often trolley wheels have lubricated bearings with a wheel bushing that turns on a fixed axle. Often these bearings are lubricated infrequently and a flat spot can develop on the axle in the journal area of contact stress. Also, other types of bearings are common, including self-lubricated bushings, roller, and ball bearings. Self-lubricated bushing type bearings should be identified, since the inadvertent addition of a wrong lubricant and/or other chemicals can actually represent the introduction of a contaminant that can result in deterioration of the self-lubricating material. Roller and ball bearings can be factory pre-lubricated and encapsulated, or set up for field lubrication. Frequently, roller or ball bearings have ring seals or diaphragms that prevent outside contaminants from entering the bearing. Over lubrication can result in dislocation of ring seals or diaphragms, which allows contaminants to enter into bearing cavities. Bushing, roller, and ball bearings should be inspected for misalignment and side movement along the shaft or axle journal. Misalignment and movement can be a sign that a bearing has become compromised.

Bearing noise is often a sign of bearing misalignment, wear, and/or contamination. Bearing noise should be an immediate indicator for closer inspection and potential maintenance.

7.6.2 Trolley axles

Axles provide a mechanism that acts to distribute live and dead hoist and gate loads to wheels, and that allows wheels to roll smoothly on a supporting surface. The supporting surface is often a steel rail. Normally an axle has two wheels, often supported by individual rails. Axles should be of a length that positions the wheels properly over the rail. The wheel tread should be in contact with the rail surface. The wheel flange, if present, should be in its proper position relative to the side of the rail. Axles should be straight, and relatively stiff. Too slender an axle when loaded to the design load can deflect causing misalignment of the wheels, bearings or drive mechanism. An axle length that results in incorrect wheel position can result is too little contact area between the wheel and rail. Wheel tread can become worn prematurely due to the high contact stresses, or unequal wheel loading.

During an axle inspection, it is important to check for straightness, and orientation of each axle. Wheels and bearings should be normal to the axle's axis. Wheels should roll smoothly, with appropriate friction for the type of bearings used. Too much wheel friction is a sign of possible wheel to axle misalignment. Often an axle requires periodic adjustment (if available) to align wheel treads and flanges to rail surfaces. Side bearings and/or thrust washers are often used to space wheels on axles. Surfaces of side bearings and/or thrust washers should not be worn or scored. Wheel adjustment (if available) is often difficult, and is seldom performed unless an alignment or rolling problem is perceived. However, periodic adjustment is worthwhile to extend the life of wheels, bearings, and axles. This is perhaps more critical on axles that are driven or motorized.

In some cases, axles are mechanically driven or motorized. This could include a chain drive, belt drive, or direct coupled drive. Unequal wear of mechanical components can be signs of misalignment or various other problems. Stiffness of drive axles is critical to proper trolley operation. Frequent bearing maintenance or replacement is often a sign of a flexible axle.

7.6.3 Trolley drives

Trolley drives can be quite simple or quite complicated depending on the trolley configuration, hoist size and capacity, and whether the trolley is required to move while loaded (with a gate). An inspector should understand how the trolley drive functions and the operating requirements. Trolley drives are required to move in two directions, which can be accomplished by a reversing transmission or by changing the direction of motor rotation. The trolley should move smoothly in either direction.

A trolley requires adequate control to position the hoist mechanism over a gate or the gate over a gate slot. As the trolley drive mechanism and brakes wear, the trolley will begin to “coast” or “drift” with positioning action. Stopping in the correct position will become increasingly difficult, but can be corrected by maintaining or replacing drive components. Coasting or drifting is usually more of a problem with higher speed trolleys. If the trolley is not equipped with a redundant brake, adding one should be considered.

Trolley drives often have limit switches at the ends of runways that kill trolley drive power when the switch is activated. This prevents a trolley from leaving the runway. Another accepted method is to provide mechanical stops that limit the trolley travel.

7.6.4 Shafts and couplings

On older units confirm that connection of the wire rope or chain to the hoist drums meets documented shaft design. On newer designs, the wire rope usually wraps onto a drum and chains are driven over sprockets or pocket wheels. Wire rope and chains should neatly fit into the shaft or drum grooves and sheaves, and the drums and sheaves should not exhibit excessive groove wear. A wire rope should have a minimum of two dead wraps around the rope drum unless otherwise specified as well as a minimum of two wire rope clamps. The teeth, hub, and keyway of a drive shaft mounted chain sprocket should not be cracked or distorted, or show signs of distress.

Drive shafts should not have any surface cracking or pitting, especially at stress concentrations such as at corners and fillets, and at keyways. A drive shaft should normally have a maximum eccentricity (i.e., radial bow) not exceeding 0.1 in., which can be accurately determined by measurements. Shaft journal surfaces mating inside bearings should not be scored, rusted or pitted.

Shaft couplings should be tight with the bolts intact, and elastomeric (rubber) flexible couplings should not show any signs of rips or tearing.

7.6.5 Gear reducers

Teeth on exposed gear drives and rack and pinion mechanisms should not show signs of excessive abrasion or wear. Teeth of mating gears should be properly aligned, show no movement during operation or backlash when starting or stopping. Gears should be well lubricated. The gear bodies should show no signs of structural distress such as cracking, especially at areas of stress concentration such as at base of teeth.

Casings for enclosed gears should be undamaged, tightly sealed, and show no evidence of leaking oil. Before operating a gear system, a small sample of the lubricating oil should be drained from the gear case. If any visible signs of condensate water or metal flaking are noted, it should be recorded and the oil changed. Breather caps should be in place and cap elements should be functional. While minor seepage at the gearbox input and output shafts is tolerable, seepage should not be enough to form a puddle. Enclosed gear drives should not exhibit signs of rough operation such as excessive noise or vibration. If these signs are present then the casing should be disassembled and the gear bearings and internal gearing evaluated.

7.6.6 Motors

The electrical inspection of motors was previously discussed in Section 7.6.2 and 7.6.3. Motors have a rated torque, horsepower, rotational speed, and thermal limit, based on certain voltage, amperage, and wattage. Variance from motor manufacturer's nameplate characteristics can result in poor motor operation, or problems. If a motor is not powered properly, it will never be able to deliver design torque or power.

In some cases, a motor will physically stall while raising or lowering a gate. This can be a result of the motor working too hard such that the thermal limit is exceeded. Motors are normally equipped with thermal overload protection; when the thermal overload is exceeded, the motor stops. In some cases, gate load is too great, and the motor cannot develop adequate starting torque to move a load. This can result in a thermal overload or motor stall. In some cases, the time required to raise or lower a gate is too long for the motor rating. The motor simply stops during the raising or lowering cycle. In some cases, motor power will change characteristics during a hoist operation because other equipment begins to operate on the same power circuit. When inspecting a motor, a review of the motor nameplate is essential. In some cases, the motor nameplate will not be legible. This should be corrected. (The nameplate should be replaced or the nameplate information otherwise posted on the hoist.) The electrical power circuit and power source should be understood by the inspector. Older hoists can have a problem due to the hoist location on the power circuit. Most hoists are located at the end of an electric circuit along with other equipment on the same circuit. If other equipment has been added, the power circuit or power source may not have been updated. Testing the power circuit for adequate capacity is recommended when there is a motor operating problem because simple motor replacement on the circuit will often not solve this type of problem.

The motor shaft should rotate smoothly without significant bearing or armature noise. A connecting drive shaft should be properly supported with a bearing either at the motor casing or adjacent to the motor coupling. Motor shaft misalignment can result in inefficient delivery of torque from the motor shaft and premature motor failure.

The motor case should be free of standing water, dust, and other deleterious material. Motors that are not used frequently can be nesting locations for insects, spiders, rodents, or birds and long-term performance can be affected. The motor armature requires air to circulate within the space between the armature and the field wiring. Air circulation provides cooling and limits temperature rise. The air space should be clear and free of deleterious matter. If dust and debris are observed, it should be removed. In cases where motors and hoist brakes are in enclosures, venting of the enclosure should be adequate for air circulation. Typically enclosure vents are screened. Enclosures are often drained to prevent standing water.

Noise can be a sign of motor problems that require closer investigation. Normally motors rotate smoothly with very little noise. Motor noise can be a sign of a bearing or other problem. If motors are required to work above their nameplate rating, or when a motor is in distress, motor noise will often increase or change in sound. Increased noise requires inspection.

Weather and temperature change can have a direct impact on a motor. An unsheltered motor located in the direct sunlight can attain a high temperature. Also, when operating, the motor thermal limit is more easily reached. Cold temperatures and radiant cooling can result in condensation within the motor casing and moisture on motor components. Driving rain and drifting snow can affect motor operations. Motor heaters and enclosures are used to protect motors in cold climates. Heaters and enclosures should be inspected and tested to ensure they work properly before each cold season. Hot or wet climates often require an enclosure to protect the motor or a totally enclosed motor case. The inspector should be familiar with these unique site conditions.

7.6.7 Brakes

Several types of motor brakes are used on hoists, including a simple leather strap and lever brake, disc style brakes, drum brakes, caliper brake, motor-brake, eddy current brake, self locking worm gears, and fan brake. Disc style brakes are the most common load brakes. The brake mechanism engages discs against a brake rotor when the brake electrical circuit is de-energized. When the brake circuit is energized simultaneously with motor power to either raise or lower the gate, brake disks are disengaged from brake rotors.

Proper adjustment of brakes is very important to hoist operation. If a brake is improperly adjusted, the gate may drift close. If a brake fails to completely release during hoisting, the motor overload protection could trip and prevent the hoist from raising a gate.

If a brake has a manual release it should be field tested to confirm proper operation. The brake mechanism cover should be removed and the mechanism examined for contamination such as sand, dirt, rust, oil, lubricant, insects, spiders, rodents, or birds. Oil and grease should be removed. Contaminated discs should be replaced. The brake pads should not be excessively worn and the rotor should show no signs of rust, pitting, or scoring. In some cases, a base has been added under the brake to support the enclosure. The base becomes a collection point for contaminants including standing water. The area around a brake should be clean and free of deleterious matter.

The drum brakes have a coil or coils, which are located on either side of the drum. To function properly the coils are configured to have an air space entirely around the coil. The air space cools the coil and prevents overheating. The warm coil attracts nesting insects. The brake coil should be inspected once a year to ensure that the air space around the coils is free. The wire insulation is in good condition and the wire connections to the terminals are firmly attached.

7.6.8 Bearings

Shaft bearings should be lubricated unless documented evidence confirms that they are self lubricating. Bearing lubrication should be field confirmed by removing a small specimen of grease from the bearings being inspected. Maintenance records should be reviewed to confirm that bearings are regularly lubricated. The type and grade of lubrication should be recorded, and its suitability for the application confirmed with the lubrication manufacturer.

Worn or broken roller or ball bearings should be replaced, preferably with either sealed or greaseless bearings. Distressed bearings can frequently be detected by either noise or heat buildup during operation. Unusual bearing heat buildup (indicating a bearing problem) can possibly be detected casually by touching the bearing housing or more quantitatively by use of an infrared camera.

Bearing housings should not be cracked and mounting and anchor bolts should be present and tight. Bearing pedestals and support structures should show no signs of structural distress such as cracked or spalled concrete or distortion in steel members.

Several potential problems can develop within a bearing from material deterioration that can significantly increase resistance to rotation. Visual inspections of bearings should note potential environmental sources that can accelerate bearing deterioration. One of the most common environment conditions to be avoided is water entering bearing cavities. Bird droppings mixed with water can be very aggressive with some bearing materials. Birds should not be allowed to roost over hoist machinery to reduce the possibility of bearing contamination. Also, bearings can be contaminated with sand and other abrasive materials. For this reason, pressure washing around bearings is not recommended since this can force-feed contamination. Water within graphite bearings can create a galvanic potential that can accelerate deterioration resulting in pitting of some stainless steel pins. On bearings with tight tolerances, some self-lubricated bearings can appear to stick as small gaps fill with particles that can swell in the presents of water. Carbon steel bearing components and water can corrode and seize if not exercised regularly.

During field inspection, observations for evidence of bearing seizing should be noted. Some newer plastic materials are now being used in heavily loaded bearings. Plastics are not as dimensionally stabile as most metals. They have a greater thermal expansion coefficient and can creep under high stress. Flow of bearing material can lead to clamping action and must be taken into consideration during bearing design. Another source of bearing clamping is misalignment. Some gate configurations result in significant deflections and movement of gate members and bearing positions. Gate systems properly aligned in an unloaded condition may not be adequately aligned once loads are applied. This can lead to misalignment and seizing of the bearing. Bushing/bearing wear is difficult, if not impossible to evaluate by visual inspection alone. Measurement of run-out, where possible is a good monitoring technique. Where run-out measurements are not possible, measurements for rotational resistance can be used along with listening for unusual noises. Chattering, banging, and uneven movement are signs of bearing wear.

7.6.9 Sprockets and drums

Sprockets and drums should not have surface cracking, distortion, or pitting, especially at areas of stress concentrations such as corners, fillets, grooving, and other machined surfaces. The sprocket and drums should rotate smoothly, and collect and store wire rope or chain properly.

Sprockets and drum couplings and other attachments should be inspected for misalignment, loose or missing bolts, cracked welds, distorted keyways, and other signs of distress. The attachment of cable/chain to drums and sprockets must be a secure connection. The reeling and unreeling of wire rope or chain should be a smooth transition from the drum or sprocket. A visual review of reeling or unreeling of wire rope or chain should be smooth and uniform.

During operation, observe abnormal rotation movement, sagging, and vibration. Also, note if the hoist is properly oriented and aligned to the gate and its attachments. When gate hoists are moved or relocated, they can be misaligned when reinstalled.

7.6.10 Chain and wire rope

The visual inspection of chain and wire rope is a very important step of a hoist inspection. Corrosion can lead to failure of the wire ropes and the connections to the gate. The wire ropes and connections must be inspected periodically and replaced if section loss is significant. In areas of severe corrosion, stainless steel wire rope may be used.

Small defects and corrosion can reduce the rated load and carrying load capacity of a chain or wire rope. More severe defects and corrosion can result in chain or wire rope breakage. The purpose of the chain or wire rope inspection is to determine if the chain or wire rope will retain sufficient load capacity until the next chain or wire rope inspection. Chain and wire rope inspections should be performed more frequently than hoist inspections. As chains and wire rope age, more frequent inspections are warranted as well.

Roller-type chain hoists are susceptible to corrosion that can cause the pins to bind and result in unequal opening of the gate. Roller-type chains should have lubrication points on each pin. Lubrication will extend the service live of the chain.

Link chain may be open link or stud link. Stud link chain was widely used in the past before newer high strength chain material was developed. Stud link chain may be die-lock or welded stud construction. Link-chains are susceptible to sudden failure due to corrosion.

It is recommended the inspectors refer to the chain and wire rope manufacturer's published inspection procedures. The latest purchase order and chain and wire rope certifications should be available to identify the chain, current government regulations, and wire rope manufacturer so that technical data is available for inspector reference. This will provide the inspector with a mechanical description of the chain and wire rope.

The inspector and operations and maintenance personnel should be familiar with the latest local, state, and Federal government regulations concerning chain and wire rope. Wire ropes and chains should be inspected above the water line monthly, as a minimum if the gate hoist is used frequently, and quarterly, if used less frequently. For a hoist used for any other purpose than as a gate hoist, more frequent inspection may be required. Some chain and wire rope may be continuously below the water line and requires inspection by a diver or underwater camera. Underwater inspections are expensive and not normally done routinely. It is recommended that an underwater inspection be done at least every five years if there is no opportunity to inspect the chain or wire out of the water. The inspection should be conducted when the hoist is at rest and the chain or wire rope is slack. Chain and wire rope should never be inspected when the hoist is operating or when the chain or wire rope is under load. Inspection of the chain or wire rope should be done individually for each chain or wire rope. The minimum acceptable inspection is visual. Each chain or wire rope inspection should be documented in writing and signed by the inspector or the operations and maintenance person responsible.

It is important to understand that chain and wire rope are consumed (wear) during hoist operation and eventually will require replacement. Chains and wire ropes are likely to be replaced one or more times during the hoist life. The original specified chain or wire rope may not have been available at the time replacement was necessary, and an “equivalent” or “higher strength” alternative could have been selected. The inspector should know and understand if the chain or wire rope has been replaced. The act of choosing a higher strength chain or wire rope may have increased the actual hoist lift capacity by default.

There are critical points requiring special attention during an inspection. These points are subject to higher stresses, wear, greater force, and other hazards. The points are:

- pick-up or gate attachment
- end attachments on hoist mechanism or other lifting point
- equalizing sheaves
- drums

- sheaves
- abuse points (contact points, radius points, catch points, trash entanglement points)
- between reservoir operating high and low water levels
- hooks
- lifting or spreader beams and slings.

End attachments require careful and close inspection. The end attachments may restrict the free movement of chain or wire rope. This loss of flexibility is often where a stress concentration will occur that breaks wires or bend chain links. End fittings are often covered with corrosion, which makes close inspection difficult. Corrosion is also a possible mechanism for a reduced cross section in chain links, wire rope, or the attachment mechanism. For proper visual inspection, corrosion must be removed.

All fasteners need to consider stress concentrations, eccentricities, splices, restraints, and fatigue. Fasteners showing wear, cracks, etc. should be identified for replacement. The proper fastener(s) need to be used. The *Machinery's Handbook* or manufacturers' literature is helpful to ensure that proper fasteners are being used.

The structural integrity of the connections to the gate is critical. Each connection must be mechanically functional, such as rotating and swiveling, yet capable of handling design loads. The loads imposed on these connections can change from initial "lift" to steady motion lifting. Gates that are infrequently operated or operated under adverse conditions (e.g., ice, debris) sometimes have "frozen" connections. Part of connection inspections is being aware of dissimilar metals, which leads to corrosive conditions.

Since most gate connections are underwater during inspection, information on this item can be obtained by:

- discussion with operating and maintenance personnel
- review of maintenance records
- visual observations during gate operations, dewatering of gate
- underwater inspections

The age, frequency of operations, impact loading during partial gate opening, and corrosiveness of water will dictate the needed frequency for the gate connection inspection Generally, a discussion with operating and maintenance personnel can provide sufficient information for inspection records. The operations and maintenance personnel are most likely to see the gate connection when the gate is in the raised position. Photographs are often used to document the condition of the gate connection when it is above water.

7.6.10.1 Wire ropes

Wire ropes and their fasteners must be capable of transferring applicable forces between the gate and the hoisting machinery. The capacity rating of wire rope must consider individual and composite strand twisting, eccentricity, stress concentrations, splices, restraints, section loss, and cyclic operating fatigue. Typically there are safety factors that are applied by hoist designers in the selection of the wire rope. These safety factors should not be compromised by any notable defect. The visual inspection should look for deficiencies and anomalies such as: abrasion, rope stretch, reduction in rope diameter, corrosion, kinks, “Bird caging” (i.e., localized expansion of the rope lay), heat damage, protruding core, damaged end attachments, peening, “scrubbing” (i.e., rubbing displacement of wires), fatigue fracture, broken wires, and accidental electric arcing. Note that a wire rope can look acceptable on the exterior, but may be compromised by deterioration within the interior areas of the wire rope. Non-destructive (e.g., electromagnetic) testing can also be a valuable tool for the evaluation of a wire rope.

The wire rope terminations, particularly connections at the gate are also frequent problem areas. Optimal wire rope material (usually plough or stainless steel) can depend on local water chemistry and on operating conditions. Water which is relatively corrosive and/or frequent gate operations will lessen cable life. Typically, replacement is the recommended maintenance for damaged lifting chains and wire ropes. Damaged chain or wire rope anchorages should be replaced or strengthened. Typically an engineer experienced in gate lifting devices/components is consulted when a wire rope or its anchorage is damaged or appears compromised. An identical replacement for older wire rope may not be available and an alternative must be selected. Experience and judgment in design and operational conditions are preferable for assessing the factors leading to determination of whether the equipment and operating conditions warrant equipment replacement or upgrade.

It is also important to inspect ancillary components such as sheaves and drums, particularly at locations of concentrated reactions such as connections. A primary factor to assess in determining the need for cable and wire rope replacement is the number of broken wires for various types of equipment, the criticality of operation, and/or if it is a moving or standing cable. Wire rope bending as it travels over sheaves and drums will cause outer wire rope wear. This is an important consideration when considering wire rope replacement.

For large diameter wire rope, wooden wedges can be used to temporarily pry some openings between the stands to observe internal cable surfaces. Older attachments used zinc to anchor wire rope into a socket. Zinc can dissolve so these types of attachments require close monitoring. Pins, eyes, thimbles, clamps, and other fasteners need to be counted and, if missing, replaced. Wear or bending can be observed and are signs of distress. When wire rope is bent into a close radius to make an eye attachment, wear or broken wires can be observed at the inner and outer circumference. These stress points are often the location of accelerated corrosion.

For wire rope, the diameter and lay should be measured. There are two type of wire rope lay, regular and lang lay (based on direction of twist). Lay is the direction in which the strands of a wire rope are twisted. In a wire rope, lang lay refers to the strands of a wire that are wound in the same direction as the wire. The wire rope purchase order will indicate whether regular or lang lay was provided. Never attempt to measure lay immediately after installing a wire rope. A rope should be allowed to initially stretch under load. When measuring lay, an average lay length is measured. Use of a tape or marking crayon is helpful when measuring lay. The marking crayon is used to follow a strand. Some inspectors use carbon paper and regular paper to make a rubbing of the lay. This provides a record of the lay condition from one inspection to the next. The changes to lay are normally gradual. If there is a sudden change, wire rope should be replaced. The diameter is defined as the distance between the outside of crown to outside of crown of the outside rope strands (Figure 7-1). Reduction in diameter can result from normal stretch, outside wear, and internal rope damage and according to the Wire Rope User's Manual replacement is recommended if the diameter reduction exceeds 5%.

Confirm that the connection(s) of wire rope to the hoisting shaft meets the documented shaft design. The wire rope should neatly and smoothly fit onto the shaft drum(s) and sheave(s). It is particularly important that wire rope not

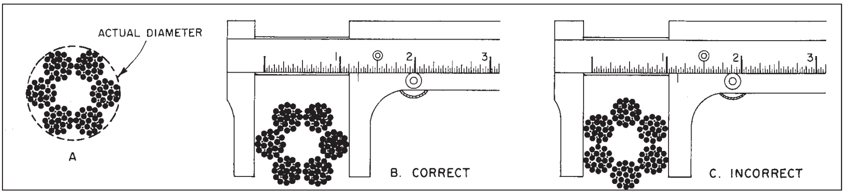


Figure 7-1. Wire rope width measurement (WRTB 2005, reproduced with permission from Wire Rope Technical Board).

wrap on itself, unless it is designed to do so in disc-layered drum applications. Wire rope which lays on top of wire rope can result in added stress to the outer wire rope strands and fibers. A wire rope hoist should have a minimum of two dead wraps around the drum unless design criterion requires more. Wire rope end connections should be intact and cable clamps tight around the entire periphery of the rope. A minimum of two clamps appropriately sized and installed is generally required. Wire rope should be checked for uniformity in loading (i.e., angle to gate), slack, and clearances to adjacent equipment and structures.

The "Wire Rope Users Manual (4th Edition)," prepared by the Wire Rope Technical Board is an excellent reference containing detailed information on the design, application, inspection, evaluation, and maintenance of cables and wire ropes.

7.6.10.2 Chains

Chains with their fasteners transfer the forces from the gate to the hoisting machinery. The capacity rating of the chain must consider eccentricity, stress concentration, splices, restraints, section loss, and cyclic operating fatigue. Chain with cracks should be replaced.

Although electromagnetic non-destructive testing can be a very valuable tool for the evaluation of an operating chain assembly, it is not a substitute for visual inspection. The visual inspection should look for deficiencies and anomalies such as: abrasion, creep/elongation, corrosion-induced section loss, kinks or other deformations, fatigue fracture, link-section reduction, and any other potential stress concentration or loss of section/loss of rotation efficiency potential. These inspections should be performed by emplacing "slack" into the chain and carefully inspecting the mating portions of adjoining links where the high contact stresses and the retention of moisture at the metal-to-metal interface can accelerate corrosion and/or abrasion loss of section and therefore initiate link cracking or other weaknesses. The inspection should include highly diligent observations within areas subject to waterline wetting/drying, which is an area particularly subject to accelerated corrosion. It is also important that ancillary components such as end terminations and drum-sprockets be carefully inspected since they are areas where stress concentrations would normally be expected and where metal-to-metal contact can accelerate wear and therefore induce additional stress concentrations and loss of section (abrasion and/or cathodic corrosion).

Generally, a significant part of the chains are beneath the water surface. Discussions with the operator should determine when the chains were fully or partially replaced (i.e., turned end for end, spliced). Since deterioration of the chains due to chemical reaction of water generally is worst near the water surface and at gate connections, the gate should be lifted periodically to expose the section of chain above and below the water line, and the gate end connection. If the gate end connection cannot be exposed, periodic inspection with a diver is recommended.

It should be confirmed that the connection between the chain and sprocket is visually satisfactory. The chain should neatly fit into the sprocket and associated guides. The chain angle and slack between the sprocket and gate should be checked for alignment and uniformity. Also, chain sizes and links need to be checked to ensure that they have the same lifting capacity (i.e., same type of steel material). Chains should have sufficient clearances between adjacent equipment and structures.

7.6.11 Rack and pinion

The rack and pinion mechanisms should not show signs of abrasion or wear. The teeth of mating gears should be properly aligned, show no movement during operation, and be well lubricated. The gear bodies should show no signs of structural distress such as cracking, especially at stress concentrations such as the base of teeth. The rack attachment bolts should be intact and tight.

7.6.12 Screw stem

The screw stem threads should not show excessive wear, damage or corrosion, and the threads should be generously lubricated with a lubricant suitable for the site specific environmental requirements and ambient temperature range. The stem should not exhibit permanent deflection or bowing. The inspection should confirm that stem guides shown on the design documentation are present, aligned, lubricated and anchored. Similarly, the base of the operating system stem should not show signs of movement such as settlement or tilting that would affect stem alignment.

Operating system screw stems can either be manually operated only or be motor driven and have a manual hand wheel for emergency operation. Gate operating systems should have a suitable means of lockout to prevent unauthorized gate movement. Similarly hand wheels or cranks that are missing (e.g., stolen by vandals) should be replaced and secured.

A screw stem system should be operated and should not show any:

- **Excessive force to open or close**. On motor operated units, the upper torque limit (generally shown on a scale of 1 to 10) should be noted and (if possible) confirmed that it has not been reset. Resetting the maximum cutoff torque upwards toward the "10" setting means gate movement is experiencing increasing resistance, implying a progressive problem with the gate or operating system. Progressive increase in force needed to move a hand-operated unit is easily detected.
- **Deflection of the stem**. Because screw stems are long slender members, they are very susceptible to compression induced buckling. Therefore, excessive stem lateral deflection (sideways movement greater than 1/240 of the unsupported stem span) can be an indication of problems such as an undersized stem, missing or deficient stem guides, or increased gate friction. Long screw stems should be checked annually for excessive deflection or missing or deficient stem guides. Friction can increase significantly in stem hoist due to a variety of circumstances, including lubrication, increased gate friction, alignment, silting, binding, etc.
- **Jerky or rough operation**. Gate movement should be smooth. Rough or jerky motion indicates a problem that will increase with time, and risk failure of gate operation. There should be stem thread left at both fully-open and closed gate positions. If the stem system is encased in a pipe sleeve that is required to be filled with oil, the oil level should be confirmed and seals should not show signs of leakage or damage.

7.6.13 Counterweights

The purpose of a counterweight on gates is to reduce the effective dead load of the gate and minimize the hoisting force required to raise the gate. This is a relatively simple system to design, install, and inspect. Inspection should determine if counterweight is properly attached to the gate and that the counterweight and counterweight supports present no obstruction that to full opening of the gate.

7.6.14 Lubrication

Lubrication is a key element for long-term satisfactory hoist operation. Lubricant should be renewed regularly, and should be free from contaminants. Lubricants and lubrication should be as recommended by the hoist manufacture. Careful inspection of the hoist components to observe oil levels and lubricated grease surfaces is a critical part of inspection to ensure that lubricated components such hoists, gears, bearings, etc. receive adequate lubrication and that lubricant is not allowed to age and become less effective.

Hoists components include bearings, gearing, wire ropes, and chains, and other rotating devices that require lubrication to operate smoothly without deterioration. Because hoists do not run continuously, they are often forgotten when it comes to lubrication. Often hoists will go years without lubrication until a hoist failure is experienced. Whether scheduled periodically or performed prior to operation, lubrication is essential to proper hoist operation.

Hoists are designed for various lubricants including grease, gear oils, wire rope, chain lubricants, etc. Hoists lubricants are generally simple, mild lubricants. As part of initial installation, and operations and maintenance instructions, the hoist manufacturer usually specifies acceptable lubricants for particular hoist components. For older hoists, these lubricants may no longer be available. Equivalent lubricants can be determined by a lubrication engineer or lubricant supplier. Modern lubricants include penetrating oils and lubricants with a variety of additives. Hoist bearings frequently dry out over time, and must be replaced during application of new lubricant. A lubrication product that leaves a residual build-up is not recommended.

It is recommended that, during each hoist inspection, lubricants be checked for water build-up, contamination, and lubricity. Lubricity is a measure of a lubricant's ability to continue providing lubrication. Tissue test of a lubrication sample can assist the inspector to determine if oil remains in the lubricant or if there is contamination due to metal filings in the lubricant. Take a small sample of lubricant from a bearing journal and place it on a white tissue. Rub the tissue softly against the sample, flattening the sample.

Oil should pass through the tissue and be exposed on the backside of the tissue. The flattened lubricant sample can be examined by a magnifying glass. The tissue sample should be compared with a sample taken from fresh lubricant. The acceptance criteria will be clear to the naked eye. If metal filings are observed in the flattened sample, the bearing or gear should be scheduled for closer inspection, maintenance, and/or replacement.

Lubricants should be fresh and offer lubrication. Also, it is useful to lubricate during hoist operation. A reduction in hoist device noise is often observed.

One can over lubricate. The manufacturer's instructions should be followed. If there is a lubrication packing gland or O-ring at the journals, care should be taken not to displace the gland or O-ring. Glands and O-rings should not be visibly displaced.

7.7 Hydraulic hoists

When hydraulic-oil hoists are used, a single lifting cylinder is usually preferred. Where dual lifting cylinders are used, synchronization of stem travel is necessary for a smooth non-binding gate motion. Hydraulic-oil hoist cylinders are reliable lifting units. Testing with instrumentation beyond that already provided with the hydraulic power unit is generally not part of inspection. The following paragraphs provide items to look for in hydraulic systems.

7.7.1 Power units and piping

The initial inspection of a hydraulic power unit (HPU) should include a visual check for leaks. The reservoir hydraulic oil should be at the proper level. The motor and pump should operate smoothly and quietly. The HPU should not generate excessive oil temperatures. Normal temperature is 100 to 120°F during operation. The system operation pressures should not exceed the design pressure. Automatic operation of the pressure switches and relief valves can be confirmed by temporarily isolating the cylinders from the HPU and operating the pump at the over-pressure limits.

Units exposed to cold winter temperatures may require auxiliary heating of the reservoir fluid to maintain proper viscosity for proper operation. The minimum reservoir fluid temperature is a function of the hydraulic oil used (viscosity vs. temperature relationship), length, and diameter of the piping between the HPU and the cylinder, and the size, pressure, and travel speed of the cylinder. Note difficulties during winter conditions.

A more comprehensive HPU evaluation should include a fluid analysis to ensure fluid conforms to original specification. A representative fluid sample should be obtained by flushing the valve for 15 sec after the system has been at the operating temperature for at least 30 min. Follow the procedures in either the National Fluid Power Association (NFPA) specification T2.9.9,"Method for extracting fluid samples from a reservoir of an operating hydraulic fluid power system," or NFPA T2.9.1, (ANSI B93.19) "American National Standard method for extracting fluid samples from the lines of an operating hydraulic fluid power system." The fluid analysis typically includes tests to:

- Confirm that fluid viscosity is within 10% of the original specifications
- Determine that neutralization number that indicates fluid has deteriorated or oxidation is excessive
- Confirm that water content does not exceed 0.5% of the fluid volume
- Obtain particle count from a 100 ml random sample to determine overall effectiveness of the filter system
- Perform a spectrographic analysis to determine the presence of required additives and contaminants.

The importance of fluid cleanliness cannot be overemphasized, since it is estimated that over 75% of HPU system failures are a "direct result of contamination" (Parker 1979).

Hydraulic hoses should not be cracked, brittle, twisted or kinked. They should have ample bend radii with sufficient slack to compensate for hose length changes during pressure (about +2% to -4%). They should be neatly installed with adequately support, and not exposed to heat above 120°F.

Piping connections should not leak and valves should be fully operational. The piping should have sufficient support so that it does not vibrate during operation. Excessive pipe vibration fatigues metal and creates leaks.

7.7.2 Cylinder

Cylinder attachments should not have signs of distress such as missing bolts, distortions, member cracking, excessive movement, or bending. Lubricated bushings must be properly lubricated at proper intervals.

If leakage is evident past cylinder and rod glands, possible sources are loose tie rods, excessive pressure (check cylinder nameplate rating with actual pressures), a pinched or extruded seal, and seal deterioration. Seal deterioration can be caused by incompatibility between the seal material and hydraulic oil, exposure to elevated temperatures, or wear due to high usage or rough rod surfaces.

Common gate configurations use hydraulic cylinders mounted between the top of the gates from supporting piers, or between downstream face of the gate and spillway from the crest. Because gate alignment and movement is critical, anchoring rods, support grout pads, and concrete for cylinders should be carefully observed for cracking and deterioration that could lead to cylinder misalignment and failure. Cylinders and support connections should be observed for looseness and misalignment such as bent rods, bent pins, and rubbing surfaces. Although it is usually difficult to access cylinders mounted on the downstream side of gates, occasional close up inspection of these cylinders is important.

The condition of the piping to crest mounted cylinders should be observed. Look for inadequacies in protection of the piping leading to the cylinders mounted on the downstream face of hinged crest gates, since a piping rupture during gate operation can be devastating. Long term deterioration of the hydraulic cylinder piping, such as leakage in concrete embedded piping, is difficult to directly detect. The most common method of inspection is to look for an unexplained loss of hydraulic fluid and/or more frequent cycling periods of the hydraulic power unit's motorized pump. There is a possibility that hydraulic fluid leakage may be noticed from the concrete covering embedded piping, most commonly at construction joints or cracks.

7.8 Pneumatic hoists

7.8.1 Air power units and piping

Air power units typically include a filter air intake, blower or compressor, and an air receiver. The filter should be periodically checked and replaced as needed. Refer to Section 7.7.6 for further coverage of blower or compressor motor inspection. Belt drives should be checked for wear and replaced as needed. Periodic lubrication schedules should be maintained. Air receivers piping often have issues with internal condensation and should be periodically drained. Air pressure gages should be calibrated periodically.

The air blower or compressor system should be checked for proper operating ranges, as recommended by the manufacturer. Take particular note to the cyclic times of the blower, since this could be a sign of blower failure or unacceptable bladder leakage. Often, there are timers on the units that give clock times on total operations.

7.8.2 Bladders

The inspection of bladders needs to focus on the key components of the anchorage system to the dam (sides and bottom) and integrity of the bladder. Often during inspection of the bladder small holes will be observed and periodic repair necessary. The climatic location and loads induced (i.e., ice, debris) along with the age of the pneumatic hoist needs to be considered during the inspection process.

If the anchorage system is accessible, the connections should be carefully examined, similar to gate clamp seals. The anchorage to the sidewalls is often subjected to major impacts, and should be carefully inspected.

Operators should be quizzed on the operation of the bladder. How easy is it to totally deflate? Do oscillations occur when it is deflated? Oscillation can result from poor hydraulics or high tailwater. Also, look for surface bubbles in the water if possible, since this could be the sign of some leakage in the bladder.

The bladder should be inspected for holes, wear (such as the result of oscillation on concrete base) and joint separation. Cases of bladders layer delamination (similar to a tire) may occur.

7.9 Monorail and overhead crane structural inspection

Monorails hoists used as gate operating systems are overhead cranes and should be inspected accordingly. Monorails are similar to single-girder overhead cranes without end trucks. As a minimum, inspections should follow Hoist Manufacturers Institute check list and ASME B30 for hoists and trolleys. Structural members and connections should be inspected per the applicable section of AISC standards. Applicable sections of CMAA specification for single girder cranes should also be incorporated as criteria.

7.9.1 Structural support

Monorails, bridge beams, other structural members, and connections are critical safety items. Failure of a support or connection could result in catastrophic failure of the entire operating system. The members supporting framework should be inspected from connection point to the monorail to the foundation. Often these members are hidden behind walls or wall panels. Inspection is nevertheless periodically recommended. Foundation and framework connections should be visually inspected. Member corrosion, distortion, or connection distress is often an early warning sign of problems.

7.9.2 Rails

Rails and rail joints should be inspected for alignment of running surface as well as gauge distance between the rails. The gauge between rails should not vary more than 1/8 in. The bottom flange of each adjoining rail should be shimmed so that the rail joint forms a continuous running surface without offset at the top and sides of the railhead. In some cases, the top of the rails will not be aligned at butt joints. A small amount of misalignment (1/16 in.) is acceptable. Often this misalignment is ground flush to allow smooth transition of wheels across joints. Bolted splices should be examined to make certain that are tight and that the hardware does not protrude into the path of the trolley wheels.

In practice, trolley wheel gauge or the distance between wheels should be checked to ensure that rail engagement is consistent. Many trolley axle designs allowed wheels to move back and forth on the axle. This would allow field adjustments to better match actual rail gage. In some cases, the inspector will observe only partial contact between the wheel tread and rail head (i.e., the centerline of the wheel will not align with center line of the rail head). This creates a potentially dangerous situation when under load because wheel/rail engagement may be lost, causing derailment. Because the wheel extends beyond the rail head, the wheel can encounter other obstacles adjacent to the rail, or create a safety problem as the trolley moves back and forth on its rail system. This also may result in derailment or personal injury.

Rail-welded splices should be examined for cracks in the welds and adjacent base metal. Vertical deflection of the track should not exceed 1/450th of the distance between the supports. Rail sweep and camber should not exceed 0.5 in. within 20 ft. Stops should be provided at the end of each continuous rail so as not to allow open ends of track. Stops on systems with motorized trolleys should be designed to maintain full integrity when subjected to impact force equal to the full rated trolley load plus the weight of the hoist and trolley traveling at maximum designed velocity. Systems with manual trolleys are normally designed for an impact of the full rated load traveling at 80 ft/min.

During visual inspection, it is recommended that the trolley be moved back and forth along its rails. Single location visual observations will not provide a reliable inspection of the relationship between the trolley wheels and rails.

In some cases, the rail will be embedded into the concrete deck with a depression on either side of the rail. The depression allows the wheel flanges to track along the rail alignment. Unfortunately, this depression becomes a collection point for debris and liquids. This depression should be debris and liquid free to avoid possible derailment.

7.9.3 Painting and coatings

Structure and rails, with the exception of running surfaces, can be protected by appropriate coating systems. Rail running surfaces contacted by trolley wheels, and trolley wheel running tread surfaces should not be painted. Frequently, the entire rails and splice plates are not painted. This is normal practice. Unpainted rails should be checked for corrosion especially at the rail base and connections between the rail base and support structure.

Trolleys and hoisting mechanisms should be painted with visible colors that contrast with the rails and support structure. Motor-driven or manually operated trolleys and hoists are often painted yellow or other distinctive color. Motor-driven or manual trolleys that are needed for 24-hr usage should be equipped with light fixtures that clearly delineate the trolley periphery. Visible, bright colors will aid in this delineation.

Under no circumstances should rail or wheel surfaces be oiled. This is to prevent attracting debris and dirt entrapment or coated with grease.

7.10 Other inspections

7.10.1 Crane inspection

Crane inspections are specialized and require trained and certified inspectors. The cranes require certification on a continuing basis with the frequency determined by the governing jurisdiction. See Appendix C for further specifics on activities related to inspecting cranes. More detailed information on crane standards and requirements can be obtained from the Crane Manufacturer's Association, Inc. (CMMA).

7.10.1.1 Crane load testing

Load testing is required by ASME standard B30.2 and OSHA regulation FAR 1910.179 when the operator is installed or the load path has been overloaded, repaired or modified.

7.10.2 Rigging and lifting beams

Rigging should be free of defects. Wire rope, chain, web slings, and harnesses should not be nicked, cut, or show excessive wear or other damage. Hooks, clamps, rings, shackles, clevises, etc. should be full section and not show significant wear or surface cracks. Rigging is often comprised of components made of high-tensile strength and relatively brittle steels. Small defects can result in sudden and catastrophic failures. Broken wires and kinks can weaken wire rope. It is recommended that owners keep information on hand regarding rated load and breaking capacity of rigging components. Often rigging manufacturers or fabricators will proof-load rigging, and copies of proof-load test results should be kept on hand for use during inspections.

In some cases, socket fittings are used to connect wire rope to rigging components. Socket fittings are often connected to wire rope either mechanically or by using a fill material such as molten zinc or epoxy resin. It is recommended that all socket fittings be visually checked. If required for underwater use, cathodic protection action can weaken and/or remove zinc from poured socket connections. Epoxy resin can become brittle and crack. Close inspection is always warranted to verify the integrity of socket connections.

Often rigging is used for more than one purpose. The rigging should be clearly marked with the load rating. It is generally recommended to use rigging specially designed for gate lifting only for this operation.

Lifting beams and lifting frames are fabricated in many configurations. Lifting beams and lifting frames are generally used to improve the aspect ratio of a single point lift, or to allow a beam or frame to go down a gate slot and connect to a bulkhead or stoplog. Lifting beam/frame operation is often accomplished under water. The lifting beam/frame has alignment dowels specifically fitted to pins on the bulkhead gate or stoplog to allow positioning of lifting hooks for engagement with lifting lugs on the bulkhead gate or stoplog. Typically, there is a mechanism on the lifting beam/frame that allows the hook(s) on the lifting beam to pivot back and forth (for engagement or disengagement). Often, there is a link mechanism that prevents hook engagement at only one side of the bulkhead or stoplog. A lifting beam/frame can have single-point or multiple-point attachment for connection to a hoist or crane. A tag line for hook action is often extended from the lifting beam/frame mechanism to the hoist deck.

Lifting beams/frames should always be inspected in the dry. Each component requires close visual observation similar to that described for rigging. Mechanical components and linkage should work freely with hand force and function as intended. The mechanical mechanism should be exercised, and (if needed) lubricated. Bushings and sleeve bearings can become fouled by water borne debris and biological growth. Wheels and rollers should rotate smoothly.

Lifting beams/frames should be stored in a manner that allows for visual inspection by the operator before each use. Finding that a lifting beam/frame is not functional after lowering it into a gate slot under water can be dangerous. Lifting beams/frames can bind in gate slots during lowering and lifting. Careful attention before entering the water can save time and expensive guide repair. Generally, lifting beams are engineered components with design and detail drawings. An inspector should understand how a lifting beam/frame functions, and also understand the action of mechanical components for engagement or disengagement to/from a bulkhead gate or stoplog. This knowledge allows an inspector to actually test each function before actual deploying.

A lifting beam/frame should only be used for its designed purpose, and should be marked to show its load rating.

7.10.3 Deicing systems

Ice loads result in stress on gate components that can lead to damage and possible failure. Ice formation can add weight to a gate, and adhere seals to sealing surfaces, resulting in overloading hoist equipment. Since ice can impact hoist equipment, lubrication systems, load transfer devices, etc., it is important to review the type of system(s) that an owner has. Heating methods for de-icing gates normally use some type heaters, bubblers, or de-icers as described in Chapter 3. If the gate inspections are done during warm weather, the inspector may not get a good understanding regarding the effectiveness of de-icing systems. The effectiveness of a heating system can be determined by reviewing:

- Operation records, particularly problems responding to early spring runoff conditions
- Maintenance records of equipment
- Review of and verification of backup plan for failed de-icing system
- Visual observation of damage to gate hoist or components
- Backup system(s) to include location and availability.

7.10.4 Deicing maintenance

Maintenance of deicing equipment is similar to other gate components. Annual inspection and maintenance is recommended. The important elements include the following as a minimum:

- Inspect equipment when removing or taking out of service at end of deicing season. Look for damaged or worn components, such as aeration pipes, propeller blades and electrical heaters. Repair or replace damaged or inoperable components so equipment is available for service in forthcoming winter.
- Have an alternative plan for rapid access to replacement parts or for implementing other deicing mechanisms in the event the primary system fails. Note that this is particularly important where freezing temperatures can result in damage to gate components quicker than replacement parts can be ordered and installed on de-icing systems.
- Test/operate the de-icing system prior to anticipated winter usage.

7.10.4.1 Heaters

Direct heat conduction devices include side and bottom seal heater elements installed in recesses adjacent to embedded sealing plates, or within gate perimeters. Also, heating elements may be installed directly on the surfaces of gate skinplates (within cavities between gate beams). Normally, heating elements are nichrome strip heaters, mineral insulated heating cables, radiant heaters, or tubular heaters. Heater cables in side walls or sill plate cavities are not normally accessible; thus, review of maintenance records, including availability and time to replace failed components must be discussed with the operators. Enclosures and heaters may be permanent or temporary. On some gates, heating is temporary. If temporary, heat lamps on extension type cords are often used. If de-icing is through the transfer of heat via circulating media (such as glycol or oil), the pumps and fluid lines need to be inspected for leaks and fluid circulation.

7.10.4.2 Air-agitation (bubbler system)

Compressed air systems release air through spaced outlets located upstream in front of the gates, generally near the bottom or at the sill line. The inspector should check the air manifold system from compressor to outlets for all gates to ensure that valving is in good condition, and is adjusted correctly for even air distribution. Compressor motor, mechanical components, air tanks, etc. should be checked, primarily by observation and by review of operation records.

7.10.4.3 Mechanical agitation

If mechanical agitation systems such as motor-driven propeller units are used, check the condition of the units for wear, excessive noise, and vibration.

8 Gate System Performance Testing

8.1 Introduction

This chapter covers performance testing and monitoring of gate systems for spillway, emergency, and intake gates, and their respective operating systems. Performance testing evaluates the entire gate and operating system in operation. Monitoring refers to observations of components during typical gate operations for the purpose of evaluating gate performance. This chapter addresses test frequency, test preparation, test procedures, suggested test equipment, and documentation of the test results.

Some owners have very definitive requirements for the supervision and management of operations and maintenance activities. It is not the intent of this document to dictate how an owner must manage and organize its operations and maintenance activities. The specific site conditions, gate characteristics, and risk/consequences of potential malfunction during performance testing should be always considered to determine the appropriate gate testing protocol.

8.2 Type and frequency of testing

The most important type of testing is periodic performance testing. Periodic testing of spillway, intake, and emergency gates is required to verify dependability of operation, and to identify requirements for maintenance. Actual gate raising and operation under full pool hydrodynamic conditions is preferred, but not always practicable. This provides the most complete verification of a gate's ability to discharge during flood conditions. When this is not feasible, such as when there is potential for adverse downstream consequences, tests at lower pool levels, under balanced conditions, or "in the dry" are valuable alternatives. These tests provide less complete information but can confirm many aspect of proper gate function.

Some spillway gates have not been operated for many years, particularly under full design head load case. Spillway gates are typically raised and lowered by wire ropes or chains and rely only on the gate weight to overcome frictional forces during closing. Spillway gate hoists are commonly powered by electric motors that give them an overload capability of 150 to 250% of normal raising torque and over time may not be suitable to lift the gates under maximum gate loading and friction. Testing of gates subject to a large differential water load may result in downstream flow damages and loss of water storage benefits including hydropower, water supply, and recreation. Consequently, many larger gates are typically tested in the dry when the reservoir is below the gate, or with upstream placement of bulkhead/stoplogs limiting loss of water, and are occasionally tested under full water load such as normal or emergency condition simulation.

8.2.1 Balanced head and dry exercising

“Balanced head” refers to conditions in which the hydrostatic forces are equal on both sides of the gate to be exercised. For emergency and intake gates, “balanced head” means that water pressure would be equal on both sides of the gate. For spillway gates, balanced head refers to operating the spillway gates in the “dry,” which means there is no water on either side of the gate. When possible, complete a dry or balanced head gate exercise prior to testing under partial or full unbalanced load.

8.2.2 Unbalanced head tests

Unbalanced head tests refer to conditions in which gate operation is conducted when hydrostatic forces are not equal on both sides of the gate. Unbalanced head performance testing is recommended for regulating flood control gates. Maintenance/dewatering gates, guard gates, and emergency closure gates are designed only for operation under balanced head conditions. Unbalanced gate exercising of emergency gates presents a higher risk of potential damage that should be considered before testing these gates.

Although full-travel testing of all gates is desirable on an annual basis, it is recognized that there may be times when continuously high reservoir water level prohibits exercising some spillway gates because valuable water storage would be lost or a destructive quantity of water would be released downstream. In such cases, full-travel testing should be postponed until the reservoir water level is lower, until the downstream channel can pass flow without damage, or until stoplogs can be installed.

The benefits of unbalanced operation should be balanced against costs and risks. Direct costs of gate testing include preparation and completion of gate exercising and loss of valuable water. Indirect costs can include risks of downstream damage, damage to the gate, jamming of the gate, cavitation, etc.

Excessive gate vibration should be avoided. It is essential to develop and follow sound test procedures to control costs. Costs of inadequate gate testing can include inoperable gates and gate structure failure, which, in most cases, are significantly greater than gate testing costs.

8.2.3 Partially unbalanced head tests

Partially unbalanced head tests refer to conditions in which gate operation is conducted with an initial unbalanced head; however, the installation of upstream bulkhead gates or stoplogs results in loss of differential head as the gate is opened. This testing sequence has the advantage of releasing only a small volume of water, can be performed at normal pool, and can be used to confirm hoist capacity and initial performance since "lift off" from the gate sill often presents the highest load. Partially unbalanced head testing is preferable to unbalanced head tests whenever adequacy of gate operation is in question and full unbalanced head testing is considered too risky a test for gates that present the potential for the loss of a large reservoir pool should the gate fail to reclose.

8.2.4 Frequency of gate exercising

All flood control and regulating gates should be operated at least once per year. The gates and their operating systems should be maintained at readiness. If it is determined that more gate exercise and testing is needed to confirm readiness, this should be considered. For gates that are continuously under reservoir load (head) with no flow, it may be impossible or impractical to move the gates through the full range. Under these circumstances, a partial opening of 1 to 2 ft is recommended instead of minimally small openings that might result in potentially damaging vibration modes. Full-travel gate operation should occur at least once every 5 years. For gates continuously holding a reservoir of substantial value, this may require bulkheads and/or waiting for spill flows. For dams with gates continuously holding valuable storage and no bulkheads or stoplogs, the owner should strongly consider the benefits of adding secondary closure capacity. Scheduling of unbalanced head testing for regulating, spillway, and other type gates will depend on the reservoir conditions and downstream requirements such as channel capacity, limited water supply, environmental, recreational, etc. Gate testing exercises should be planned to fit into regular scheduled maintenance activities of the facility. Gate testing can often be scheduled concurrently with required preventative maintenance. Gate exercising under unbalanced head conditions is recommended at least once every 5 years. However, the scheduled interval

Table 8-1. Suggested gate exercise frequency.

Gate Type	Balanced Exercise Frequency[a] (years)		Unbalanced Test Frequency (years)
	Partial Open/Close	Full Open/Close	
Flood Control	1	5	5[b,c]
Regulating	1	5	5
Maintenance and Dewatering[d]	N/A	Prior to use	N/A
Emergency closure	1	5	As deemed applicable

[a] Unbalanced testing or operation meets the requirements of a balanced exercise.
[b] Test may or may not be full travel.
[c] As allowed by pool height or normal spillway discharge.
[d] Dewatering gates are typically only used for maintenance and are operated under balanced head conditions.

for individual gates should not exceed 10 years. Table 8-1 shows recommended maximum intervals between gate exercises.

8.3 Pre-test preparation

A successful gate test should start with the development of a test plan. This section describes various items that need to be considered. The plan must be flexible enough to consider additional work that may be required as a result of deficiencies discovered during gate testing.

8.3.1 Review gate design and safety

Thoroughly review design data, drawings, and construction data. Address all safety concerns and issues and prepare a job hazard analysis.

8.3.2 Previous test and incident reports

Previous test and incident reports should be reviewed for any indications of unusual gate operating incidents that could lead to potential problems. Reviewers should also compare the current condition to that described in previous reports.

8.3.3 Scheduling

These tests should be scheduled to coincide with favorable reservoir level conditions and downstream flow requirements. Water releases affecting downstream stakeholders should be coordinated. If the testing of gates under balanced and unbalanced head conditions can be scheduled to coincide with the regular maintenance schedule of the facility, the combined efforts can often be performed more efficiently.

8.3.4 Air vent analysis/inspection

Adequacy of the air vent capability is critical. Emergency closure of a gate under full flow and maximum head conditions coupled with an undersized or blocked air vent could result in collapse of the conduit downstream of the gate. If possible, an inspection of the air vent pipe and valves should be performed before performing closure tests of an emergency gate. An analysis or verification of vent capacity is advisable before testing. In the case of a concrete tunnel, the procedure for dewatering the tunnel may include a limit on the rate of dewatering. Exceeding this limit might damage a tunnel liner, even if the air vent is adequately sized and working correctly. Tunnel wall porosity and long term leakage might result in external water pressure behind a tunnel liner that could cause collapse.

8.3.5 Performance test plan

The purpose of gate performance testing is to document safe, reliable, efficient, and acceptable operation at a single point in time. Therefore, a well thought out performance test plan is a critical part of a gate test. All interested parties must be consulted prior to conducting on-site testing to develop a performance test plan that efficiently and completely satisfies gate test goals. A list of equipment required to perform the gate tests should be included in the plan.

8.3.6 Monitoring plan

The purpose of a monitoring plan is to establish a continuing process for confirming gate performance over time. Observations and notes are typically recorded in a log. A written monitoring plan highlights critical physical, hydraulic, and structural operation gate performance characteristics that should be monitored each time a gate is operated.

A monitoring plan is based on the specific gate arrangement and operating requirements. Monitoring may include visual observations or actual measurements to record movement, deflection, wear, alignment, corrosion, abrasion, cavitation, distortion, vibration, noise, etc. Changes over time can be an indication of a developing gate problem.

8.4 Gate test procedures

Performance adequacy of spillway, regulating, guard, and emergency closure gates should be determined during on-site examinations. Gate testing and observation through the full range of operation is not always practical because of conditions at the dam including: restrictions on downstream flow requirements, ongoing maintenance, loss of water and power revenues, etc.

The following procedures are recommended for testing the performance of a gate:

- Equipment operation should be discussed with appropriate operating personnel (including the plant manager or owner) with sufficient lead time so that necessary arrangements for water release can be scheduled.
- Performance monitoring should be established with sufficient lead time to procure testing equipment and assign responsibilities for data collection.
- Any gate operation performed during an examination should be in accordance with standing operating procedures and performed only by trained operators, such that the operator's capabilities and the equipment performance can be observed under normal conditions.
- If a full-range travel of gate testing is possible, have operation performed using:
  - Primary power.
  - Auxiliary power (to the extent that maximum power load is not needed)
  - All methods of control such as local, remote, and automatic.
- If full-range travel of gate testing is not possible:
  - Initially, verify in logbook or other documentation the result of the most recent full-travel operation by field personnel.
  - Use primary power to operate the gate to the extent possible.
  - Use auxiliary power to operate the gate to the extent possible, or at least to a level that demands the largest power output by the auxiliary power system. This is usually, but not always, achieved during unseating of the gate).
  - Operate gate using all methods of control such as local, remote, and automatic.
- A plan should be in place to address inability to close an opened gate. The options for minimizing consequences will vary depending on the gate and project specifics. See 3.10.1 for further discussion.

The recommended test procedures for gate testing are broken out into two separate categories: one for spillway gates and another for regulating and emergency closure gates. Following each test procedure are sections for particular types of gates and the items to take note of during the tests.

8.4.1 Spillway gate performance testing

Good operation and maintenance practice requires that each spillway gate be exercised periodically to confirm that it will operate as designed. To meet this requirement and minimize the risks involved, it is recommended that the following procedures be performed.

Each spillway gate should be exercised annually while subjected to the maximum head available for the season to verify that it can satisfactorily open and close. If properly monitored and documented, gate operation during seasonal high water releases can be substituted for dedicated gate testing. This gives the advantage of full gate travel testing without significant downstream impact or loss of reservoir volume.

Spillway gate performance testing should be conducted as follows and in the order listed:

1. **Partial-Travel Test Operation**. Open the gate 10 percent or a minimum of 1 to 2 ft of its full travel, then close it. This should be done with some experienced judgment since small gate openings can induce potentially damaging gate vibrations. If it has been more than a year since the gate was operated and the gate has unknown or suspect operating capability, the 10% travel shall be made in progressive steps. If it is not possible to open a gate 10% due to restrictions on releases, then open the gate as much as possible and then close.
2. **Full-Travel Test Operation**. The gate and operating systems should have previously passed a visual inspection and the partial travel test operation. Raise the gate to the fully open position or the maximum allowable opening and then lower the gate to a fully closed position.

If the gate malfunctions during the test-operations, stop the exercise and attempt to determine the cause of the malfunction and correct it. Continue the gate exercise if conditions are acceptable; otherwise, schedule the gate and/or hoist for repairs. Repeat the gate exercise after completing the repairs.

Satisfactory partial-travel gate test-operations under differential head conditions generally confirms hoist capacity for full-travel operation since maximum loading often occurs during unseating of the gate. However, partial-travel exercising does not ensure that the gate can be physically operated through a full-travel test-operation without binding.

Spillway gates that have not been operated full-travel for five years or more because of a continuously high reservoir and lack of stoplogs should be addressed on a case-by-case basis. Estimated costs and impacts of alternative testing protocols need to be evaluated. Following visual inspection and evaluation, a determination should be made of the practicality of performing actual full-travel test-operation. Such test-operation will require careful monitoring to detect developing problems and allow for a safe abort of the test. Additional standby personnel and equipment should be considered to address potential problems, particularly if the pool level or gate opening is a new maximum. If full-travel gate-testing is not deemed necessary, indirect means should be provided for checking the capability of full-travel operation of the gates. Indirect assessment to verify conformance with design drawings may include surveying the position of gate bay walls, embedded wallplates, and pedestals, measuring clearances between the gate faceplates/guide shoes and bay wall or embedded wallplates, and underwater inspections of wire rope connectors.

8.4.1.1 Drum gates

Drum gates should rotate smoothly, without binding through full travel raising and lowering. Test operation should verify that the controls are performing satisfactorily. Leakage should be low enough as to not adversely impact gate operation.

Drum gates should be set to regulate flow and should be checked to see if the set position holds steady.

8.4.1.2 Radial (tainter) gates

Radial gate performance testing should be conducted annually with special attention given to trunnion bushings. Gates should be operated with full (preferred) or partial travel as conditions allow. Movement should be smooth without sticking or binding, differential movement, or chatter.

8.4.1.2.1 Gate performance testing

In addition to trunnion bushing testing, the following observations should be considered when testing gates:

- Lifting symmetry
- Lifting effort
- Noise
- Vibration
- Eccentric movement (runout) of rotating components.

Radial gate components with anticipated changes in performance over time are:

- Side roller contact with piers
- Side seals contact with wallplates
- Alignment of lifting wire ropes/chains
- Trunnion alignment, support and anchorage systems
- Debris accumulation
- Wave overtopping
- Changes in reservoir operations.

Measuring lifting effort is recommended to monitor for gate sticking or binding that could be related to alignment or side wall contact issues. However, lifting effort does not have adequate sensitivity to accurately monitor performance of trunnion bushings friction. Lifting effort can be monitored by recording motor voltage and current, or by installing load cells on the chains (or wire ropes) or under the hoisting equipment.

Side rollers in heavy contact with pier walls can result in redistribution of forces that were not accounted for by the original designers. Proper gate alignment should result in contact of side rollers with pier wallplates on one side of gate bay only. Side rollers should roll freely and be free from flat spots, which would be an indication of seized bushings.

Other important observations to include in performance testing of radial gates are measurements for uneven lifting. This can be accomplished by surveying each end of the skin plate prior to initial lift and at intermediate hold points at partial gate openings. In addition to surveying the skin plate, uneven lifting can be identified by watching if the initial water release at the sill progresses from one side of the gate to the other or begins evenly across the entire gate width.

Noise and vibration observations should be included in an overall performance testing plan and can be an indication of gate and/or bushing sticking, binding, or clamping.

8.4.1.2.2 Trunnion bushing performance testing

For many years it was not unusual for radial gate designers to ignore trunnion friction when sizing structural column members. Even when friction is included in analysis, an assumption of worst case performance is required. Since trunnion pin/bushing performance changes with age and deterioration, it is prudent to regularly monitor trunnion friction changing conditions.

Several factors can degrade bushing properties over time:

- Wear and inadequate lubrication
- Contamination from dirt and debris
- Clamping due to buildup of corrosion products
- Changes in alignment
- Deterioration from galvanic action or chemical attack
  - Graphite and water can corrode stainless steel
  - Bird droppings and water can create ammonia, which can deteriorate brass or bronze

Interior surfaces of trunnion bushings require difficult disassembly to inspect; therefore, performance testing is considered the best way to determine current condition and to track change, which allows for planned maintenance.

The installation of strain gages on the trunnion arms allows monitoring of radial gate trunnion bushing friction. The combination of a repeatable monitoring system with a onetime installation of strain gages can result in an economical system with meaningful action and threshold limits. The installation of a monitoring system to measure deflections without initial strain gage testing is an effective technique for noting changing conditions and is considered adequate only in cases where structural factors of safety are sufficiently large as to obviate the need for highly precise monitoring.

The following testing sequence should be considered to evaluate trunnion brushing friction:

- Unbalanced head testing (full dynamic testing)
- Partially unbalanced head testing (dump tests)
- Balanced head testing (dry testing).

Balanced head strain gage testing give base line strains related to dead weight and static load conditions. Partially balanced head testing can be used to determine hydrostatic components. Unbalanced head testing combined with balanced head testing allows a complete understanding of dynamic effects on gate arm columns due to changes in trunnion friction.

8.4.1.2.3 Trunnion monitoring

A radial gate bushing monitoring system needs to be able to identify changing conditions, but may not quantify the structural implication of the changes. A simple monitoring system includes an alignment laser placed on the trunnion with a target attached to the skinplate. By regularly recording laser movement, changes in arm column deflection can be measured and documented. With experience, this data can be used to interpret effects of trunnion performance related to frequency of gate operation, lubrication procedures, water levels, and environmental conditions.

The following equipment can be used to monitor trunnion bushing performance:

- Alignment laser and target
- Ultrasonic measurements
- Dial gages
- Level surveys.

8.4.1.2.4 Monitoring instrumentation

In addition to trunnion bushing monitoring, other monitoring may include recording hoist amperage and line voltage. Although the hoist amperage and line voltage not provide an accurate measurement of trunnion bushing performance, it is a simple and repeatable method to monitor overall gate operation for unexpected changes. Recording of gate run time, total travel time, water level, and number of start/stops can be useful in predicting future maintenance. This information can be gathered manually or automatically with position and operational sensors mounted on the gate.

8.4.1.3 Ring gates

Ring gates should be operated through full travel; the gate should move smoothly without binding. These performance tests should verify that the controls are performing satisfactorily.

The ring gate should also be set to regulate flow. Check to see if the gate holds a steady position or tends to "hunt." If the gate hunts, the controls should be overhauled.

8.4.1.4 Roller-mounted gates

Operate the roller gate under maximum head through full travel and ensure that the gate moves smoothly and without binding, that the hoist functions properly, and that the wheels have not developed flat spots or bearing degradation.

8.4.1.5 Hinged crest gates

Confirm that the cylinders on a particular gate have simultaneous rod extensions and rates of movement so that the gate is not subjected to twisting or warping. A common method of testing is to observe uniform flow over the gate crest at initial overtopping. Also look for side seal binding and be aware of any non-uniform movement during travel.

8.4.1.6 Inflatable gates

Determine if leakage exists in the piping and/or bladders that make up the air operating system. Use manufacturer's specifications to determine if bladders maintain inflation for adequate time.

8.4.2 Regulating and emergency closure gates

To ensure full reliability of regulating and emergency closure gates, testing under balanced and unbalanced head conditions is necessary. Testing is critical to verifying reliability to operate under emergency conditions.

8.4.2.1 Roller-mounted gates (Stoney, Caterpillar, Tractor, Coaster)

1. Operate emergency closure gates through full travel under balanced no-flow conditions, if possible. Ensure that the gates move smoothly and without binding and that hoists operate properly.
2. Operate emergency closure gates through an unbalanced closure test under maximum flow conditions after checking that the air vents are adequately sized and correctly functioning. Ensure that the gates and hoists operate properly.

8.4.2.2 Wheel-mounted gates

1. Operate emergency closure gates through full travel under balanced no-flow conditions, if possible. Ensure that the gates move smoothly and without binding and that hoists operate properly.
2. Operate emergency closure gates through an unbalanced closure test under maximum flow conditions after checking that the air vents are adequately sized and correctly functioning. Ensure that gates and hoists operate properly.
3. The wheels should bear against rails and roll freely as the gate travels up and down. Gate seating should be checked by closing the gate, dewatering the downstream conduit, and observing the amount of leakage past the gate.

8.4.2.3 Slide gates

1. Operate slide gates through full travel under balanced no-flow conditions, if possible. Ensure that gates move smoothly and without binding and that the operating system (lift) functions properly.
2. Operate emergency closure gates through an unbalanced closure test under maximum flow conditions after checking that the air vents are adequately sized and correctly functioning. Ensure that gates and hoists operate properly.

8.4.2.4 Ring-follower and ring seal gates

1. Ring-follower gates are prone to cavitation; therefore, excess vibration or noise during the operation should be noted.
2. Before any unbalanced test, confirm that the downstream vent or air vacuum valve is correctly sized and correctly functioning.
3. Operate gates through full-travel under full head unbalanced conditions and note performance parameters such as smoothness of travel. The condition of the seats should be checked by noting amount of leakage when the gate is fully closed.

8.5 Gate operating systems

Gate operating systems fall into two general categories – hydraulic and mechanical.

8.5.1 Hydraulic gate operating systems

8.5.1.1 Pre-operation checks

1. Check the reserve oil level through the sight gage. Make sure that the oil level is above the minimum and below the maximum allowable level.
2. Check the temperature of the oil with reservoir-mounted thermometer. Review the instructions from the power unit manufacturer regarding operation under various temperature ranges. Normally the cartridge heaters are provided with the power units to automatically heat the oil when its temperature goes down.
3. Check supply or return line oil filters for clogging. An appreciable pressure drop across a filter as indicated by pressure gages, indication lights, or audio alarms is an indication that the filter needs cleaning or replacement.
4. Check pressure settings of flow control valves, relief valves, and pressure switches to ensure intended performance of hydraulic power unit. Also, check that valves and fluid lines are securely mounted, and that nuts and screws are tight.

8.5.1.2 Performance test – hydraulic moist mechanisms

1. Switch on the hydraulic pump. Verify that the pump starts in the unloaded position and generates oil pressure corresponding to the system relief setting after a time delay. If the pump pressure is lower than the pressure setting, check the pump and power unit. The amount of gate opening should account for other considerations such as gate vibration. Gates may need to be raised more than "a few inches" for this test to be performed safely.
2. Operate the hoist for gate opening. Check the operating pressures and current draw for gate operation. Visual checks will also be made for possible leakage in the power unit.
3. The cylinder rod should not have rust or pitting. Extend the rod and confirm that it is not rusted, pitted or permanently bowed. During the cylinder push stroke, observe the amount of rod bowing and erratic movement. Bowing can be a sign of problems such as binding, bearing, deterioration, excessive friction due to cylinder misalignment, undersized cylinder for the load or the stroke length is too long.

4. Verify synchronous movement of all cylinders for a gate during operation and note binding or rubbing that occurs. The measurement procedure in Section 8.8.1 can be used to verify synchronous movement.
5. Once the gate has stopped, hold it in its current position for few minutes. Check the gate for drifting due to leakage past the piston and hydraulic valves. If the drift is visible (approx. 2 in. for 24 hr is generally permissible), the hydraulic hoist and power unit should be overhauled to control the leakage. Cylinder drift is caused by leakage either through the piston seal or the directional valve spooling. One method to check for a piston seal leak is to pressurize one side of the cylinder piston and disconnect the opposite port fluid line. Leakage through the downstream ports of the directional control valve can be similarly detected. Directional valves inevitably exhibit some leakage if the gate's hydraulic cylinder is pressurized for long periods of time. Therefore, either pilot check valves and/or a hydraulic loop to the pressure side of the valve are installed.
6. Again operate the gate, note the oil pressure, and stop to check for internal or external leakage. This process should be repeated one more time.
7. Close the gate. Follow the same sequence and checks as for opening the gate. Verify that the gate automatically stops at the fully closed position, sensed either through the limit switches or a position-indicating device.

8.5.1.3 Performance checks – hydraulic power unit

The following checks should be made during the performance testing of the power unit.

<u>Oil leakage</u>

1. Check for oil leakage at cylinder rod end seals, fluid line connections, control valves, and oil reservoir. Leakage (internal or external) will prevent maintaining desired gate position for long periods.
2. Most oil in use is mineral oil. Since it is not environment friendly, measures should be taken to prevent spillage.

<u>Pump motor</u>

1. Verify that the motor is securely attached to the HPU frame, coupling nuts and bolts are tight, and pump and motor shafts are aligned.
2. Check motor current voltage draw for comparison with rated load current draw. Also, check the motor for overheating, noise, and vibration.

Pressure at pump and cylinder

1. Verify that the oil pump starts in an unloaded position and generates the full oil pressure corresponding to the relief valve setting.
2. Check the oil pressure at the cylinder ports when gate operation is initiated and compare it with the normal operating pressure. Higher operating pressure typically indicates a higher operating load.
3. Check for pressure relief on return. When the gate operation load is too high, the cylinder piston will not move and pump discharge will be returned to the oil reservoir through the pressure relief valve.

Hydraulic valves

1. Check the hydraulic valves for proper operation. Compare the various pressure gage readings to offset faulty readings from an impaired gage.
2. Check manual shutoff valves for proper open and closed positions.
3. Check the various valves for oil leakage. Check solenoid valves for overheating and humming noise.
4. If the gate is operating too fast or too slow, necessary changes should be made in the flow control valve's setting.

Proximity or limit switches

Limit or proximity switches are normally used to regulate the end of the stroke for both opening and closing of the gate. Verify that the gate is fully open or fully closed at the ends of the stroke.

Position indication

Verify that the gate position indication device works throughout full-travel gate operation. The position shown on the control panel and actual gate position should match within permissible tolerances.

Drift control system

1. If a drift control system is provided to prevent gate movement from its fully open position, verify that it functions automatically and restores the gate position when drift exceeds a predetermined value. Some drift control systems function from accumulator press and never allow any drift.
2. Verify the system alarm when gate drifts more than allowed.

Synchronization of two or more cylinders

When a gate is operated by two or more hydraulic cylinders fed from the same or different power units, check for synchronization of cylinder travel. Verify that the cylinders start and stop at the same time and operate at the same speed.

8.5.2 Mechanical gate operating systems

8.5.2.1 Wire rope and chain hoists

Pre-operation checks

Typically gate hoists are checked by raising the gates from a closed position. The gates are lifted under balanced head condition (when possible) and then under unbalanced load conditions where applicable. Before moving the gate, if there is a slack tension connection (e.g., wire rope or chain) condition, the operator shall determine that the tension mechanism is properly seated on the drum. Loose or slack wire rope and chain should be adjusted and tightened prior to operation. Additionally, check the following items:

1. Worn, corroded, kinked, and/or crushed strands of wire rope
2. Cracked or worn drums or sheaves
3. Deformed, cracked, or corroded members
4. Loose bolts or rivets
5. Worn, cracked, or distorted parts such as pins, bearings, shafts, gears, rollers, locking and clamping devices, etc.
6. Worn chain drive sprockets and drums
7. Corrosion between chain links and chain stretch.

Performance test

1. Raise the gate an incremental but safe level considering vibration, downstream effects, seal damage, etc. This shall be repeated at least two more times to test the hoisting on each drum, operation of clutches, brakes, locking, and safety devices.
2. Check the hoist motor current for overloading.
3. Lower the gate in the same sequence as for opening the gate. Verify that the gate does not accelerate and that the brakes are adequate to hold the gate at a given position. The gate should automatically stop in the fully closed position by actuation of limit switches.

4. Verify that there is no sudden acceleration or deceleration of the gate during each movement.
5. Verify synchronous gate movement of operator attachments, and note any binding or rubbing that occurs.
6. If testing a new or repaired hoist, check for full-travel gate raising and lowering on each drum, operation of clutches, brakes, limit switches, and locking and safety devices. The trip setting of limit switches shall be determined by tests under no load conditions.
7. If the hoist is a variable speed type, then tests shall be conducted at slow speed first, with increasing speeds up to the maximum speed.
8. Rated load tests shall be limited to 110% of the rated capacity.

Performance checks

The following checks will be made during performance testing of the hoist.

1. **Electric motor.** Check motor voltage and current draw for comparison with rated values. Check the motor for overheating and vibration.
2. **Gear reduction**. The gear reduction mechanism shall run smoothly without hesitation or vibration.
3. **Guide wheels and sprockets**. The chain should travel through the guide wheels and sprockets without hesitation. It should sit uniformly inside the teeth and flex freely, wrapping around the sprocket radius without hanging up.
4. **Wire rope and drum**. Tension devices (e.g., wire rope or chain) should wrap uniformly around drums. Chain links should rotate freely. Wire rope stretch should be checked by confirming a uniform lift.
5. **Limit and torque switches**. Verify that limit switches are functional and that they automatically stop the hoist motor and gate in fully opened or fully closed positions. Torque switches can be checked by reducing the torque setting until they trip, then returning them to an operational setting.
6. **Guide rollers**. Hard contact of side and guide rollers can redistribute gate stresses and increase hoisting loads. Rollers should rotate freely and have no more than light contact throughout their travel without significant changes.
7. **Transfer rod or drive shaft**. Rotating components should turn freely without binding, chatter, runout, and excessive noise and with only minor amounts of play. Clutch mechanisms should operate smoothly and not slip under load.
8. **Brake**. Brake should hold gate in raised position with no slippage. The braking mechanism shall be capable of holding the gate and hoist mechanism

in position without slippage for a reasonable time period. If the gate will not stop smoothly or does not stay in position when stopped, then the brakes may need to be serviced.

9. **Position indicator**. Verify that the gate position indication device works throughout full-travel gate operation. The position shown on the control panel and actual gate position should match within permissible error.

8.5.2.2 Screw stem hoist, operating system, or lift

Pre-operation checks

Visually check to make sure that the gate and operating system are free of any obstructions and are ready to operate.

1. Check the gear box for proper level of lubricating oil. Quality of oil should be checked for breakdown, discoloration, and presence of metal wear.
2. For sub-surface installations where water level rises above the Operator's floor, check the lubricating oil for the presence of water, which may have seeped into the gear box due to stem seal failure.
3. Check for proper lubrication between the actuator nut and screw stem. The stem should be fully coated with good quality lubricant.
4. Check the gear box and surrounding area for oil leakage/spillage. If oil leakage is detected, check the gear box oil seals.
5. Check the anchorage. All anchor bolts and nuts should be tight.

Performance test

1. Operate the hoist to open the gate 10%. Verify that the gate is held firmly in a stopped position. Continue opening the gate and verify that actuation of the limit switch automatically stops the gate in the fully open position.
2. Repeat the same procedure for closing the gate (i.e., lower 10%, then continue lowering to the fully-closed position).
3. If the hoist is not frequently operated during normal service, test operation should be carried out for a minimum of three cycles.

Performance checks

The following checks are to be made during performance testing of the hoist.

- **Actuator motor**.
  - Operate the actuator motor for three full cycles (as conditions allow) and compare the motor current draw with the rated full-load current.

  - Check for actuator motor noise and vibration, which may be a sign of misalignment, lack of lubrication, or loose foundation bolts.
  - Check the gate operating speed against design speed. Significant difference in speeds may be the result of improper selection of gear reducers.
- **Screw stem**. Check for wear of screw threads. Verify that there is no appreciable play between stem screw threads and thrust nut threads.
- **Limit and torque switches**. Verify that limit switches are functional and that they automatically stop the hoist motor in the fully opened or fully closed position. Adjustments should be periodically made to the limit switches.
- **Position indicator**. Verify that the gate position indication device works throughout full-travel gate operation. The position shown on the control panel and actual gate position should match within permissible error.

8.5.3 Controls

Pushbuttons should depress smoothly from the out-position to the in-position and should not stick. Some older hoists have toggle style switches. Poles of these switches can move out of alignment or become worn with continued operation. The toggle switches should be opened and closed, and switch movement observed. Engaged poles should be observed for alignment and wear. The switch should be open and closed, and the switch movement observed.

8.5.3.1 Power, start, stop, raise, lower switches

The inspector should verify the hoist operates with power, start, stop, raise, lower switches. If indicator lights are provided, these should also be checked for function.

8.5.3.2 Local/remote switch

The inspector should verify that the hoist operates in the local and remote modes. Where there are indicator lights to indicate local or remote operation, check for operation of the lights.

8.5.3.3 Travel limit switches

The inspector should allow the hoist to be operated through a complete gate cycle (raising and lowering). Verify that the limit switches stop the gate in the desired locations. Adjustments should be periodically made to the limit switches.

8.6 Control and warning systems

An important aspect of performance testing is to confirm that gate controls and warning systems are functional. This is particularly important for gates that are remotely and/or automatically operated.

Operation of safety warning devices that alert both downstream, and upstream personnel, such as boaters and fishermen, of pending gate operation should be confirmed. This includes items such as on-site horns, flashers, as well as any remote dispatch alarms. Video surveillance equipment is becoming more common both for security as well as public safety concerns.

Correct operation of remotely operated gates should be confirmed by on-site personnel during performance testing. This includes verifying collaboration of any devices where output is used to control gate operation. For example, remote output of water elevation gauges used to control gate operation should be confirmed with visual observation of actual water level. Field verification of remote sensor output is particularly important where automatic operation is involved.

8.7 Auxiliary power systems

8.7.1 Power transfer switch

Verify capability of switch to transfer operation of hoist system from primary power source to auxiliary backup power source. Switch should be used for transfer to backup power source used to operate gates.

8.7.2 Engine generators

Manufacturers issue specific maintenance and testing instructions for each of their engines. They give detailed procedures to be followed for starting, stopping, and running, and they provide necessary information regarding capacities, clearances, pressures, and temperatures. These instructions should be followed for reliability and efficiency. The following are general guidelines for performance testing of a common engine generator:

8.7.2.1 Pre-operation checks

1. **Fuel oil system.** The fuel oil system, including tanks, should be checked for the presence of water and sediment. Abnormal pressure drop across the filter indicates the need for cleaning or replacing of filter cartridge. Fuel injectors should be checked for the presence of dirt or other foreign matter and for proper adjustment. Note that old fuel can clog fuel filters and prevent full-load operation of engines. Symptoms may not be present at idle speed.
2. **Lubricating system.** Check lubricating oil for the presence of impurities.
3. **Cooling water system.** Verify that there are no system leaks and that coolant circulation is consistent with the manufacturer's recommendations. The water should periodically be tested and treated to ensure that it is clean from harmful alkalis or acids.
4. **Air intake and exhaust system.** Verify that air intake and exhaust system are clean and unrestricted, and that louvers operate as intended.
5. **Electric system.** Check motors, generators, contactors, switches, and starters for cleanliness and operational readiness. Electrical connections should be tight. Batteries, if used, should be fully charged and filled with water to the proper level. Replace batteries on a regular schedule to avoid starting failure during an event requiring backup power.
6. **Generator and exciters.** Check generators and exciters for the presence of dirt, oil, grease, moisture, and other contaminants that may inhibit operation or damage equipment. Stator ducts and coil interstices should be clean to prevent restricting flow of ventilating air, which would result in overheating of windings. If shorts or ground faults are suspected, generators may need to be Megger tested.

<u>Performance testing</u>

1. Test conditions: Operating conditions such as the loads, speeds, type of fuel, grade and type of lubricating oil, water and oil temperature, etc. should comply with manufacturer's general recommendations.
2. Schedule of tests: Standard tests shall be as follows:
   a. During each test period, readings (identified below in 3. Measurements, Observations, and Data:) are to be taken and recorded at 15-min intervals and at the beginning and end of the test.
   b. A test during a 10% overload condition if the generator manufacturer guarantees his equipment for such overload.
   c. Engine-generator test shall be performed as a part of gate testing to confirm the ability to power gate operation.

   d. Before each test, the engine generator should be brought to steady state speed under the load condition of test. The following electrical loading should be followed:
      (1) 15 min at no load, performed at least once a month
      (2) 1 hr at three-quarter load twice a year
      (3) At least 1 hr at full load at least once a year.
      (4) It is preferable that the gate hoist can be operated using the backup generator.
3. Measurements, observations, and data:
   a. During testing, check for symptoms of poor operation such as abnormal engine sounds, smells, unaccountable speed changes, unusual temperature, unusual pressure readings, etc. If the engine generator does not operate properly, it should be stopped as soon as practicable. Water circulation should be continued long enough (at least 10 min) after the engine has been stopped to allow cool down before any access covers are removed. The following observations should be made and compared with manufacturer specifications:
   b. Pressures:
      (1) Lubricating oil at inlet to engine
      (2) Jacket water at inlet to engine
   c. Temperature
      (1) Lubricating oil at inlet to engine
      (2) Engine coolant
4. Governor test: This test is conducted to measure the speed changes on the engine to determine the performance of governing equipment. The test will require a tachometer or speed recording equipment having a sensitivity of 0.25% with rating curve established for $\pm$10% of normal speed.
   a. Test methods: Bring the engine to normal speed without load and observe the behavior of governor. Measure engine speed by gradually applying load without adjustment of the governor.
   b. Steady-state operation: There should be no irregular speed fluctuation with constant load and the engine running at normal speed. Under variable loads, departures from normal speed should be minimal and return to steady state.
   c. Speed regulation: With the engine loaded to 100% of its rating, adjust the governor to the rated speed. No further adjustment will be made to the governor during this test. Slowly reduce the load on the engine to no load and note the speed.
   d. Momentary speed changes and recovery time: The speed regulation is measured by suddenly removing or adding load to the engine generator.

Recovery time is measured as the time from the initial load change until speed reaches and stabilizes within the prescribed speed band.

8.7.3 Hand pumps

Hand operated pumps serve as standby power source on hydraulic systems for emergency gate operation when primary power input is not available. Hand pumps are usually piston type. Occasionally, they are constructed with two pistons working in push and pull combination. Hand pumps can generate up to 10,000 psi of hydraulic pressure; however, pump discharge generally is a few cubic inches per cycle. The volume of the oil pumped per stroke is normally 2 to 4 cu in. depending on the required discharge pressure. The higher the pressure; the lower the pumped oil volume. The manual effort applied will be in proportion to the hydraulic pressure required to open the gate and the pump discharge per cycle.

8.7.3.1 Pre-operation checks

1. Check that the operating lever is properly connected to the piston and fulcrum. Pin joints should be fully lubricated and provided with locking devices.
2. Verify that suction port of the hand pump is below the reservoir oil level.
3. Check that the hand pump inlet valve is fully open. Verify that check valves, relief valve, and pressure gages in the hydraulic circuit are in working order.
4. Verify that there is no fluid leakage.
5. Check the relief valve setting if provided with the hand pump. The setting should be approximately 10% above the normal gate cylinder operating system.

8.7.3.2 Performance test

1. Move the manual pump operating lever by hand or foot, depending on the operation. Verify that the hand pump generates pressure and that the gate moves slightly from its initial position. The number of strokes required to move a gate will depend on the diameter stroke length of the hydraulic cylinder.
2. If there is no oil pressure, the hand pump oil pressure is lower than gate operating pressure, and/or the gate does not move after repeated strokes, recheck the relief valve setting and verify that the hand pump inlet valve is fully open. If problems persist, the hand pump may need repair or replacement.

8.7.4 Handwheels/manual operation

Most screw hoist actuators allow manual gate operation during primary power failure. If the hoist is dual operating (i.e., electrical and manual), electrical and manual features will be isolated. A hand lever will shift the operating system from power to manual mode.

8.7.4.1 Pre-operation checks

1. Verify that the handle is secured and keyed to the rotating spindle.
2. Check the gear box for proper level of lubricating oil. Quality of oil should be checked for breakdown, discoloration, and presence of metal wear.
3. For sub-surface installations where water level rises above the Operator's floor, check the lubricating oil for the presence of water, which may have seeped into the gear box due to stem seal failure.
4. Check for proper lubrication between the actuator nut and screw stem. The stem should be fully coated with good quality lubricant.
5. Check the gear box and surrounding area for oil leakage/spillage. If oil leakage is detected, check the gear box oil seals.
6. Check the anchorage. Anchor bolts and nuts should be tight.

8.7.4.2 Performance test

1. Rotate the handwheel or crank to open the gate. Estimate the force required to move the handwheel. With moderate effort, an average person can expect to exert approximately 40 lb on the rim of the handwheel or crank. If the required effort appears higher, check the gear box for bearing failure, improper lubrication, or misalignment of spindle or gears.
2. Fully open the gate by handwheel operation. If practicable due to time, effort required, or discharge considerations, a gate should be opened approximately from 10% to 50%. Smaller gates (e.g., 36 × 36 in.) should be opened to 50% of full travel, whereas larger gates (e.g., 144 × 144 in.) may be limited to 10% of full travel. Depending on the size and capacity of the hoist, full manual opening of a gate may take from a few minutes to a few hours.
3. Observe handwheel operation for noise, vibration, jerking, and anything less than smooth operation. Problems may be due to a faulty gear box, insufficient lubrication, or the presence of stem and stem nut wear. Gate movement can be sensed by gate position indication or by the height of the screw stem (if equipped with a transparent stem cover).
4. Hold the gate in the open position for a few minutes. Verify that the gate does not close due to gate weight and that the screw threads are self locking.

5. Rotate the handwheel or crank in the opposite direction to close the gate. Verify that the gate moves smoothly and sits in the closed position.

8.8 Miscellaneous tests

8.8.1 Gate misalignment

Misalignment of a gate can have a substantial impact on the gate and/or gate frame loads. Misalignment can be caused by or increased by differential loads at transfer locations (trunnions, bearings, racks, rollers, etc.), inside seal friction, and non-uniform lifting. At worst, misalignment can bind and prevent gate movement or cause structural damage. For gates designed to be overtopped, they can be lowered to pool height and observed for simultaneous overtopping along the gate's crest. Note that this method only allows one check against the current water elevation. A simple method of measuring existing misalignment at multiple gate positions is to measure the distance from each end of the gate to fixed points, then lift the gate 1 to 2 ft and measure again (Figure 8-1). Where possible, it is best if one measurement is taken when the gate is in a resting position. The procedure is more fully explained in the Corps of Engineers technical reports. The documented procedures include tainter (radial) gates (Greimann, Stecker, and Nop 1995) and roller (drum) gates (Greimann, Stecker, Kraal, and Foltz 1997), but can be adapted for other gate types.

8.8.2 Wire rope slings

When testing or using a wire rope sling, if a swivel hook experiences rapid turning while applying load this is an indication of internal deterioration of the wire rope sling.

8.9 Documentation

8.9.1 Performance test record

Following the completion of the performance test, the test summary should be recorded in the project operating log for the facility. The log should include the names of those performing the test, the date of the test, pertinent data such as opening/closing times, hydraulic system operating pressures, motor amperage and voltage readings, reservoir elevation, and other pertinent observations. The log should also indicate where a copy of the detailed test record is filed.

Figure 8-1. Tainter gate non-uniform lift misalignment measurement.

8.9.1.1 Supplementary test records

Field and plant personnel often perform many of the operational tests as a routine part of their operation and maintenance duties as defined in standing operating procedures. If outside testing personnel are satisfied that routine operation of mechanical equipment by field and plant personnel is reliable, and that operating personnel can effectively operate equipment in an emergency, outside testing personnel may consider routine operations as valid for their own testing requirements provided the following criteria are met:

- Test operations were observed and monitored.
- Test operations are thoroughly documented.
- Test operations were performed within specified time intervals specified for gate tests.

8.9.2 Test reports

The test report should also include information recorded in an operational and maintenance log, as well as additional details of the test procedure such as the test conditions, steps on the process, measurements, and unusual events.

8.9.3 Database

A test report will document results of current testing, but will not provide comparison to results of past tests. Establishing a database of operational test results where subsequent measurements are tabulated, and preferably graphed, will facilitate measurement monitoring for trends and anomalies.

9 Evaluation

9.1 General

The evaluation phase of the condition assessment of existing water control gate and operating systems involves comparing results of inspections with gate engineering standards and requirements. This includes all aspects of structural, mechanical, controls, electrical, functional, and operational systems.

9.1.1 Types of assessments

Although the intent, complexity, and details of an evaluation can vary greatly depending on specific gate configuration and the site conditions, assessments can be classified into two types called "general" and "detailed."

9.1.1.1 General assessment

A general assessment evaluates the overall condition of a gate to determine conformity with established documentation (i.e., was the gate built as designed). This type of assessment involves overall visual observation of gate and appurtenances with comparison to established documentation such as design drawings and equipment material lists. The assessment includes a review of gate operation, maintenance procedures, and conformance records. A general assessment can include a relative comparison of multiple gates to prioritize further detailed assessment. Features of a general assessment include:

- Confirmation of gate design to established documentation
- On-site observation of gates and appurtenances for condition of maintenance, test operation, and/or verification of operational records
- Documentation of observation
- Remediation and/or follow-up action (as appropriate).

9.1.1.2 Detailed assessment

A detailed assessment evaluates specific aspects of a gate to determine its adequacy and functional operation (i.e., was the gate correctly designed). Detailed assessments are usually initiated as the result of either potential problems identified in a general assessment, or specific problems encountered during gate operation. Features of a detailed assessment include:

- Determination of gate safety requirements
- Determination of the appropriate gate loads and operational conditions (see Chapters 2, 3, 4)
- Visual inspection and test-operation (see Chapter 5, 6, 7, and 8)
- Structural evaluation
- Mechanical evaluation
- Electrical and controls evaluation
- Functional evaluation
- Determination of the significance and root cause of identified problems (e.g., inadequate design, unusual loading, unusual site conditions, inadequate maintenance, training, etc.) of problems
- Life extension concerns
- Documentation
- Remediation and/or follow-up action (as appropriate).

9.2 Loads and load combinations

Before a detailed evaluation of a water control gate can begin, the various loads and load combinations acting on the gate structure and support components must be identified and evaluated. It is important that all requirements from governmental regulators, such as FERC or state dam safety offices, be considered when evaluating a particular gate.

The loads imposed on an individual gate need to be accurately identified as a function of site conditions, configuration, and operation. For example, a wheel or slide gate with an upstream skinplate and upstream seal configuration has minimal downpull and uplift forces compared to a gate with a downstream skinplate and seals. Similarly, abandonment of a filling valve or bypass line, used to equalize hydrostatic forces on a gate, would induce significant new gate frictional forces during operation that were not historically present.

9.2.1 Loads

The basic loads acting on water control gate are given below. These loads act in various combinations resulting in critical loading cases for the gate. The primary applied loads, affecting the major structural elements are hydrostatic, ice, debris, seismic, snow, wind, and temperature. Induced loads from hoisting reactions include friction, downpull and/or uplift, and seal loads. Note that there is an interdependence between primary applied and lifting loads. The structural adequacy of gate members must satisfy combined load stresses.

9.2.1.1 Hydrostatic loads

The primary load acting on gate structure is the hydrostatic loading due to differential water head pressure. Hydrostatic loading acts perpendicular to the gate surface to which it is applied. There are four types of hydrostatic loads, depending on free water surface and gate geometry:

- **Triangular load**. This would occur on faceplate of a flat gate where the maximum water surface is not above the top of the gate.
- **Trapezoidal load**. This would occur on the faceplate of a flat suberged gate (with vertical or inclined orientation).
- **Uniformly distributed load**. This would occur on the faceplate of a deeply gate where the pressure increase from top to bottom of the gate is negligible compared to submergence depth.
- **Curvilinear triangular load**. This would occur on the faceplate of a curved gate. (With overtopping flow, load would be curvilinear trapezoidal.)

9.2.1.2 Triangular and uniform loads

Figure 9-1 shows the triangular and uniform hydrostatic loads resulting from the linear variation of pressure between the highest and lowest points of submergence. Trapezoidal hydrostatic loads are similar, except that the top of the gate is submerged. Gates that are deeply submerged compared to the vertical incremental pressure increase on the gate skinplate essentially experience a uniform hydrostatic load (usually for loads greater than fifteen time gate height). Vertical flat gates experience only horizontal loading. Inclined flat gates experience a normal load that can be resolved into a horizontal component load and a vertical component load.

Figure 9-2 shows a curvilinear gate. Curvilinear gates experience a normal radial load. If skinplate radius of curvature is constant, the resultant water load vector is directed through the point of curvature, with no uplift or downpull force on the gate leaf. The resultant load vector F_r can be resolved into the horizontal component F_h and a vertical component F_v.

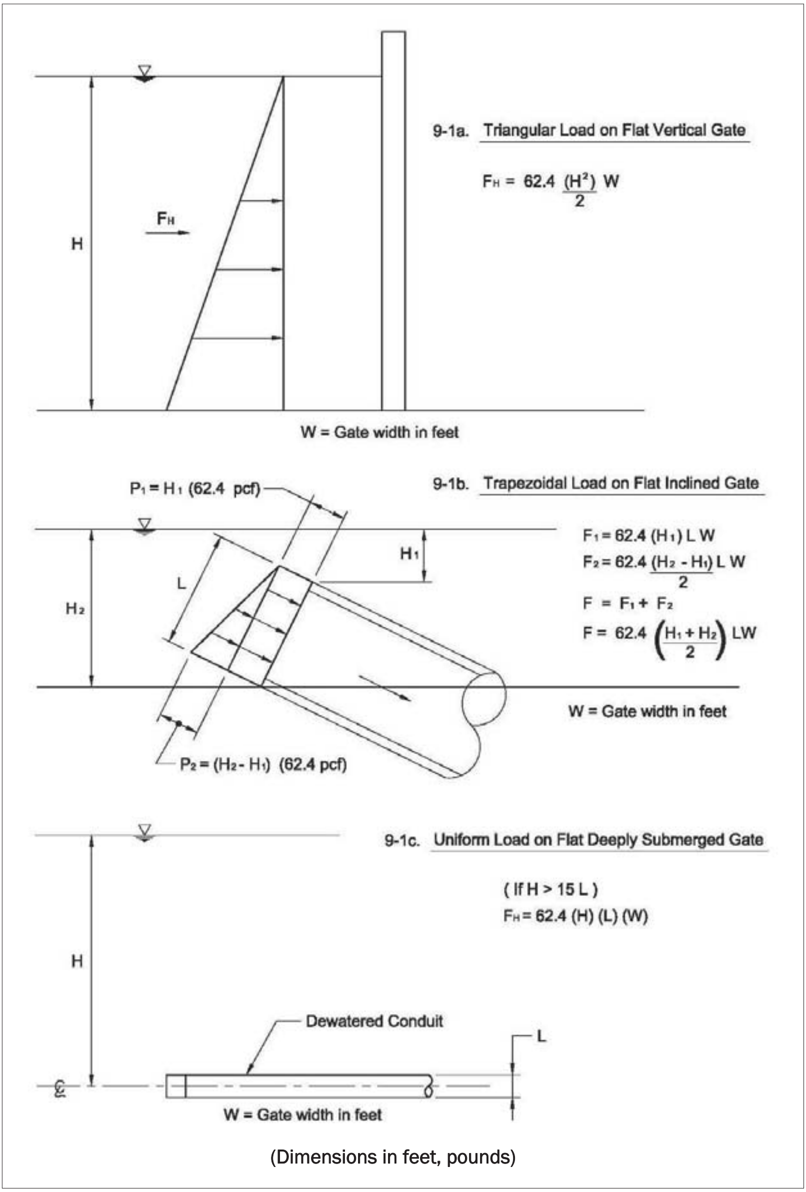


Figure 9-1. Triangular and uniform loads.

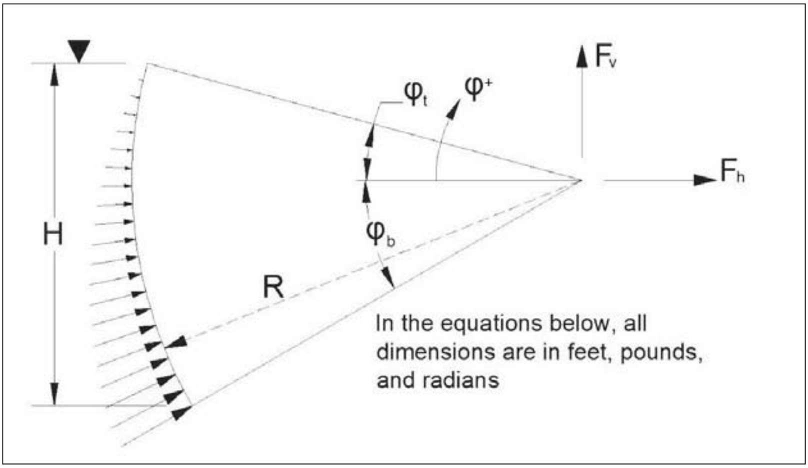


Figure 9-2. Curvilinear hydrostatic loads.

The direction of the vertical force will be indicated by sign of solved equation for F_r, (+) for up and (–) for down.

9.2.1.3 Curvilinear loads

The curvilinear triangular hydrostatic load has zero pressure acting at top of gate and reservoir head pressure at the crest elevation. A curvilinear hydrostatic load differs from a triangular load because, in addition to the horizontal load or the vertical height of the skinplate, there is a net vertical force (upward or downward) on the curved skinplate due to the sum of the downward weight of water acting above the leaf skinplate and the upward buoyant force of water below the leaf skinplate. Equations for horizontal and vertical forces acting on a curved leaf skinplate are:

$$F_h = (62.4*W*H^2/2) \text{ or } (62.4*W*R^2/2)*[(\sin(\varphi_t)-\sin(\varphi_b))^2]$$

$$F_v = (62.4*W*R^2/2)*[\sin(\varphi_b)*\cos(\varphi_b)-2*\sin(\varphi_t)*\cos(\varphi_b)+\cos(\varphi_t)*\sin(\varphi_t)+\varphi_t-\varphi_b]$$

Where:

W = the overall width of the gate in feet
H = the vertical height of the gate in feet
R = radius of gate
φ_b, φ_t, φ^+ = See Figure 9-2 (in radians).

The hydrostatic loading is illustrated in Figure 9-2. Appendix D provides further explanation of the derivation of these equations.

9.2.1.4 Water levels

A gate's critical hydrostatic pressure depends on the maximum differential between the upstream and downstream water levels. This can occur at less than the maximum upstream flood levels for gates with a downstream hydraulic control that experience high tailwater during periods of higher gate discharge. Also the maximum upstream water level for surface gates is sometimes increased by temporary splashboards or flashboards, and the gate hydrostatic loadings that these can induce before they tip should also be included in the evaluation.

9.2.1.5 Ice loads

9.2.1.5.1 Ice dynamic loads

The possibility of freezing conditions that can result in ice sheet impact or thrust on a gate, or ice sheet thermal expansion must be considered in gate structural design and operation. Ice loads could result in particularly large reactions on wide gates with top sections fabricated as long cantilevers. Leakage or overspray can also result in accumulation of heavy gravity ice loads on downstream gate members.

The Army Corps of Engineers Engineering Manuals and FERC Engineering Guidelines suggest design loads at various reservoir elevations as high as 5,000 lb per linear feet of gate width for ice sheet thermal expansion loads. The gate ice loading may vary considerably depending on site conditions. A gate heater or a bubbler system may be needed to prevent ice from being in solid contact with gates and imposing ice sheet thermal expansion loads.

9.2.1.5.2 Operating system ice static loads

Ice loads can also present significant load increases to gate operating systems, including:

1. Weight of ice on a gate structure may exceed hoisting capacity, rendering the gate inoperable in an emergency.
2. Overspray may freeze and lock the gate to the pier walls making it immovable.
3. Leakage may freeze the gate to embedded wallplates, making it immoveable and/or resulting in torn or damaged seals. Gates with wallplate heating

elements should not experience ice bridging between the gate structure and pier walls.
4. Gates that freeze in a partially open position could drop unexpectedly when ice melts.

9.2.1.6 Seismic loads

Seismic loads on a gate structure and resulting stresses and displacements need to be analyzed. Seismic loads for areas of low activity (where detailed site specific seismicity studies are not available) can be determined using procedures and locational risk maps such as those included in the ASCE Standard 7 "Minimum Design Loads for Buildings and Other Structures" (ASCE-7) or from the U.S. Geological Survey (USGS), through URL: http://www.earthquake.usgs.gov/.

Before applying seismic loads to gates in areas of high seismic activity, either a probabilistic or deterministic seismic hazard analysis is performed for the dam site to identify potential seismic faults and their associated magnitudes. Peak ground accelerations are then determined specific to the site.

Seismic loads on a gate are commonly analyzed by the pseudo static method. The pseudo static acceleration is applied in the upstream-downstream direction and resultant loads are superimposed with non-flood high-water loads. Cross-channel or vertical seismic loads are usually neglected except for unique cases, such as a radial gate with heavy ballast or with very long and heavy members. However, loads in the cross channel direction from earthquakes can be significant for gate supporting structures.

The pseudo static acceleration for gate design is usually selected based on a fraction of the peak ground acceleration (PGA). Generally, the gate design earthquake is based on the Risk Targeted Maximum Credible Earthquake (MCE_R), which is taken as one-half to two-thirds of the site PGA.

Amplification of ground motion to the vertical location of gate anchorage can be significant and must be considered in instances where gates are mounted on more flexible structures (e.g., arch dams). For more rigid structures, such as gravity dams, gate-specific amplification can be determined using Chopra's Method ("Simplified Earthquake Analysis of Concrete Gravity Dams" by Gregory Fenves and Anil Chopra, American Society of Civil Engineers Journal of Structural Engineering, Vol. 113, No. 8, August 1987, pp. 1688–1708). Gate location amplification for more flexible structures is typically determined from a finite element analysis, or from ASCE-7 in lower seismic areas where the gate supporting structure appropriately matches a code recognized support system. Both the weight of the gate and the hydrodynamic effects of water against the gate need to be considered.

One conservative, quasi-static technique for developing pressures to simulate the hydrodynamic water load on structures is the Westergaard method presented in the USBR publication entitled "Design Criteria for Concrete Retaining Walls," and also "Design of Small Dams." The technique develops an equivalent hydrodynamic force against a rigid structure by computing a parabolic pressure distribution. A modification of Westergaard's method that incorporates the flexibility of the gate is presented in a paper titled "Seismic Considerations in the Design of Gates" by M. Kaltsouni, M. J. Morgan, and C. K. Sehgal, included in the Proceedings of the ASCE Waterpower 1999 Conference. Differences in the hydrodynamic load on the gates could be significant when a simplified Westergaard equation is used versus an exact solution. Consequently, one should carefully consider whether the simplified or the detailed approach is appropriate.

For seismic areas with very high ground accelerations or when the gate is judged to be significantly flexible, a response spectra analyses can be used. However, special care must be taken in considering the direction of the load for curved surfaces such as on radial gates. The Westergaard's quasi-static approach accurately applies horizontal pressures. The component normal to the skinplate should be applied. Note that most commercial software applies the force resulting from the added mass in the direction of acceleration, which might not be the direction normal to a surface.

After assumptions have been made regarding the gate characteristics, acceleration direction, and return event of an earthquake, then the various seismic gate loads can be applied. Those loads would include the seismic acceleration in the desired direction, and associated water load during an earthquake.

Depending on the uncertainty in seismic assumptions, it may be prudent to determine the sensitivity of the seismic analysis results to these uncertainties by comparing several seismic analyses using different upper and lower bound values.

9.2.1.7 Dead loads

9.2.1.7.1 Structural load

The dead load is the effect of the gravity induced weight of the gate and its components on the internal stresses in structural members.

9.2.1.7.2 Hoist capacity load

Gate dead weight becomes important when designing and sizing components for the hoisting equipment. The dead weight of individual gate components is used when computing gate center of gravity. The overall center of gravity is important for locating hoisting equipment and for determining any effects of eccentricity such as whether suspended gates will hang plumb from supporting stem or wire ropes.

9.2.1.8 Snow and wind loads

Although snow loads are typically not significant on water control gates, under special circumstances, the additional weight of snow added to the gate dead weight could result in over-stressing the structural component(s), or increasing overall lifting load beyond the rated capacity of the hoisting equipment. This has been known to occur at gates where the reservoir is drained in the winter and the gate is susceptible to snow drifts.

Wind loads only occur on dewatered gates, and are rarely a critical load. The most likely occurrence of a significant wind load is for the structure supporting a gate raised above the water surface and/or above deck in a storage position.

Typical snow and wind loads can be obtained from common structural codes such as ASCE 7, and the International Building Code.

9.2.1.9 Temperature and expansive loads

A temperature loading of a gate and/or a gate-supporting structure is induced by expansion (or contraction) of a member as a result of temperature changes if that member is constrained against movement (by anchorage or frictional resistance between parts).

Each gate application and installation should be evaluated for the possibility of temperature loading. The most typical problem is thermal expansion induced interference between the gate and guides that restricts or prevents gate travel. Temperature loads have not generally been a concern because gates are shaded by surrounding structures, cooled by water, or not restrained and have the ability to expand as necessary. Concrete cracking can occur at gate slots that do not have sufficient rigidity to resist thermal movements from decks rigidly attached to gate piers.

Gate operational problems may arise where gate slot clearances have been reduced due to alkali aggregate silica reaction (AASR) induced concrete expansion or other expansive concrete conditions. AASR is caused when concrete aggregate with excessive chemical alkali slowly reacts with water and expands. Because it is typically impractical to eliminate concrete exposure to water, the primary mitigation approach for existing gate structures is to accommodate continued expansion by providing additional clearance. This is accomplished by trimming the edges of the gate or by cutting slots in adjacent concrete to accommodate continued expansion.

9.2.1.10 Friction loads

Friction loads primarily affect the sizing of the hoisting equipment, and to a lesser degree can affect structural behavior of the gate. Friction loads resist motion between two mating surfaces. The direction of frictional forces is opposite to the direction of gate motion, and the direction reverses when the direction of gate travel reverses. The usual types of friction loads occurring between mating surfaces in control gates are:

- **Pin friction**. Friction that develops between mating surfaces of a pin and a trunnion corresponding bushing, such as a steel trunnion pin rotating inside a bronze bushing for a radial gate.
- **Rolling friction**. Friction that develops between a wheel or roller and the corresponding rolling surface, such as a precipitation hardened stainless steel wheel rolling on a stainless steel track for a wheel-mounted gate.
- **Sliding friction**. Friction that develops between a bearing bar and corresponding seat bar or guide, such as a bronze bearing bar sliding on a stainless steel seat bar for a slide gate.
- **Seal friction**. Friction that develops between a seal and the corresponding sealing surface, such as a neoprene music-note seal bulb sliding on an embedded stainless steel wallplate for a radial gate.
- **Breakaway friction**. Breakaway friction is dependent on the type of gate seals and seating wedges (where used). Appendix A in the AWWA C 560

Specification empirically assigns one half of the gate slide weight to represent the frictional effect of wedges on cast iron sluice gates.

Use free body diagrams to accurately incorporate friction loads into an analysis of gate operating forces for both opening and closing conditions.

Friction loads vary considerably depending on the design and materials used for gate components, and the actual condition of contact surfaces. It is important to use friction values representative of the actual gate being evaluated, which for older gates can be higher than friction values for new gates with lesser friction-inducing materials. Because surface condition and actual coefficients of friction generally can only be approximated by professional judgment (based on reported values of laboratory tests), the sensitivity of an analysis to a possible range of friction loads is commonly evaluated by comparing different load cases using a range of maximum to minimum friction coefficients.

For example, on radial gates, the trunnion coefficient of friction used to calculate the friction forces and moments is an assumed value. However, a higher than assumed coefficient of friction could occur for aged trunnion pins fabricated from plain carbon steel that has become corroded, or for old-style bushings containing graphite-inserts that may have promoted galvanic corrosion and pitting of wetted pin surfaces.

Attention should be focused during the gate inspection to look for conditions that may be inducing a higher than normally assumed coefficient of friction. In the absence of a gate or material supplier test to determine the actual coefficient of frictions (for a specific gate installation), the following coefficient of friction values are generally accepted within the hydro-electric industry with some of them previously published (Zipparro 1993, ch 17; Avallone 2011, ch 3):

- Plain bronze bushing on steel: Assume coefficient of friction is 0.5
- Lubricated bronze bushing on steel: Assume coefficient of friction is 0.3
- Self-lubricating bushing on steel: Assume coefficient of friction is 0.1 (when new) to 0.3 (when characteristics and contamination suspect)
- Ultra High Molecular Weight (UHMW) on steel: 0.15
- Wood on steel or cast iron: 0.5 to 0.8
- Steel on Steel or cast iron: 0.7 not rusted to 1.0 rusted.

Although currently not common, it is possible to perform field tests to obtain data to back-calculate the actual coefficient of friction of a specific gate. A common technique for vertical lift gates is to determine the actual force needed to move a gate, and then, knowing the gate dead and water pressure loadings, to calculate the effective coefficient of friction. Another approach for radial gates is use of strain or displacement gauges mounted on the arm columns to determine strain and deflection when the gate is raised and to then calculate an effective coefficient of trunnion friction based on member displacement. Side seal friction and other unusual loads such as misalignment must be considered.

9.2.1.11 Downpull and uplift loads

Downpull and uplift forces typically occur on wheel mounted gates and high pressure outlet gates installed either on the face of a dam or within the entrance transitions. The magnitude of hydraulic downpull and uplift forces is a function of the net head, gate configuration, slot and guide geometry, and flow conditions. These forces result from pressure changes due to the flow of water underneath or over the top of the gate leaf. Downpull load is a reduction in the gate's upward buoyant force due to the lower bottom pressures presented by the high velocity flow under the gate. When the skin plate and seals are on the downstream face of the gate, the gate and operator need to resist the differential pressures between static water on the top of the gate and the reduced pressure from the flowing water underneath the gate. Conversely, when the skin plate is on the upstream face of the gate, uplift load is the relative increase of upward buoyancy force on the gate's bottom compared to the gate's downward dead weight with only atmospheric pressure on the gate's top.

Numerous sources have addressed the topic of downpull/uplift forces in greater detail including charts for dimension less downpull coefficients. An available source for details is: USACE Hydraulic Design Criteria Sheets 320-2 to 320-2/3; and the Bureau of Reclamation's Research Report No. 4, "Hydraulic Downpull Forces on Large Gates" that is available from the Bureau's website at: http://www.usbr.gov/pmts/hydraulics_lab/pubs/REC/RR04.pdf

9.2.1.12 Seal loads

Seal load friction forces are induced via gate movement and result from the interaction of the neoprene or rubber side seals sliding on embedded mating sealing surfaces. Seal loads include hydrostatic pressure and an initial seal deflection; friction forces are induced with gate motion.

A maximum coefficient of friction of 1.0 is commonly assumed between a rubber seal and the guide (Zipparro 1993, ch 17; Buckhorn pp 13). The load from an initial seal deflection of a typical J bulb seal can be calculated as the amount of force required to deflect the seal stem. The stem of the seal can be modeled as a cantilever beam using the seal material properties. Similarly, the force from deflection of a center bulb seal supported on both sides can be modeled as a simple supported beam. A typical modulus of elasticity for gate rubber and neoprene material seals is 900 psi.

9.2.1.13 Misalignment and eccentricity loads

Existing gate members that become distorted can experience additional forces that must be taken into account when analyzing the strength of an existing gate.

Connections where member loads do not focus through a common point of transfer may experience induced eccentric loading. This type of secondary load is important and should be taken into account at points of concentrated load transfer such as gate lifting lugs and trunnion anchorages.

Uneven gate lifting caused by differential lengths and/or tension of gate lifting elements can cause guide roller loading and redistribution of trunnion forces. Trunnion loads can be affected by deflection of support girder assemblies causing eccentric loading that must be evaluated. Sweep and camber of main compression members can cause significant eccentric loading and should be considered along with P-delta secondary effects, such as described in the AISC steel specifications.

9.2.2 Load combinations

After basic load cases have been identified and evaluated, gate structure and hoist need to be evaluated based combined loads. In many instances, the hydrostatic loading is the critical gate load.

9.2.2.1 Normal load combinations

“Normal Load Combinations” are the sum of basic loads appropriate for a specific structure. Normal Load combinations commonly consider hydrostatic loads with the gate at rest, and operating loads with the gate moving. The two basic loads always included in load combinations are:

- Hydrostatic load due to reservoir head acting on the gate skinplate
- Dead weight load of structural members.

These two loads are combined with the effect of friction loads induced when moving the gate with maximum reservoir head. For example, on radial gates side seal friction and trunnion pin friction can both be important when lifting the gate.

Where applicable, other loadings may be combined. These may include:

- Ice
- Snow
- Debris
- Mud
- Temperature
- Wind.

9.2.2.2 Gate seismic loads and combinations

The "Seismic Load Combination" is the sum of basic loads (previously addressed) acting on a gate at the time of a seismic event plus the seismic effect. Assumptions need to be made regarding the gate position and reservoir conditions at the time of the seismic event. For instance, if it is typically reasonable to assume a reservoir water surface at the top of the gate, but that the gate would be closed and not operating during the seismic event. Typically seismic load combinations should include full reservoir head but not frictional, wind or other intermittent loads.

Where pseudo-static ground acceleration is less than 0.2 g seismic, load combinations are generally not critical combinations. For moderate seismic areas with ground acceleration up to 0.5 g, seismic loads in the downstream direction are applied to both gate weight and hydrodynamic forces. For high seismic areas with ground acceleration above 0.5 g, or when the gate is flexible, an acceleration response spectra or time history analysis can be used.

Also, the return period of the seismic event is a critical component of the seismic forces that needs to be considered in the load combinations. As an alternative to the proposed response spectra analysis, a time history analysis could be implemented for the gate/dam/reservoir interaction. Amplification of the dam acceleration as well as relevant site-specific seismic information and relevant code requirements, such as ASCE-7, should also be considered.

Eight seismic loading combination cases are possible for the two horizontal directions (X and Z) with the various weighted directional factors intended to account for multi and intermediate directions:

$$\pm 1.0X \pm 0.3Z \text{ and } \pm 0.3X \pm 1.0Z$$

Also, for high seismic areas a vertical component should be included as appropriate.

9.2.2.3 Flood load combination

The "Flood Load Combination" is similar to the "Normal load combination" except that the maximum differential head across a gate should be considered. Although flood loading occurs during rising reservoir levels, if the gates experience high tailwater, the maximum head differential may be less at a lower than for normal full-head hydrostatic loading.

9.2.2.4 Hoist equipment load combinations

The "Hoist Equipment Load Combinations" are the force balance and summary of forces used to size the hoisting equipment for a gate. This involves determining the actual unfactored force required to operate a gate, and then confirming that the hoisting capacity exceeds the required operating force. The force balance should be evaluated for both gate lowering and gate raising scenarios. For each scenario, operating forces should be evaluated for three cases: (1) Gate in maximum downpull position and unbalanced pressure, (2) Gate in maximum uplift position and unbalanced pressure, and (3) Gate in nearly closed position just prior to seating closed.

The vertical forces examined should have proper signage indicating whether a force is acting in an upward or downward direction, and should include:

- Gate weight both in air and submerged
- Weight of gate operating stem system
- Hydraulic downpull force
- Hydraulic uplift force

- Frictional forces
- Ballast forces
- Buoyant forces
- Counterweight forces
- Other loads.

9.2.2.5 Example load gate combinations

Regulatory agencies may have additional loading combinations which should be considered when evaluating various types of gates. Table 9-1 lists example possible load combination factors for radial (tainter) gates that the USACE includes in their evaluation as summarized in EM 1110-2-2702, Jan 1, 2000. Other regulatory agencies may have other load combination factors that should be considered when evaluating other types of gates. Other types of spillway gates should be evaluated using similar criteria.

9.2.3 Hoist support structure

The hoist support structure should be capable of supporting the maximum possible load that the operating system is capable of producing. Note that this force is frequently in excess of actual forces required to operate a gate, and includes consideration of upper limit operating system forces such as motor stallout and excessive manual handwheel loads. Although load limiting devices can be an economical method of limiting the upper bound on operating capacity, the reliability, control redundancy, and consequence of limiting device failure needs to be considered. For example, a hoist support structure that supports a motorized gate operating system may experience motor stall torque reactions if the gate becomes jammed. Therefore, under these conditions the operating system support structure should be designed for the motor stallout load unless there are at least two independent load limiting devices. Similarly, hoist support structures with manual handwheels should be designed for the maximum rated load provided by the operating system manufacturer with at least a 60-lb force on the handwheel (or higher if cheater bars might possibly be used).

Evaluation of the hoist support structure should include applicable dead, impact, wind, and snow loads. Applicable transverse and lateral loads should be included in support analysis. Structures supporting motorized hoists and cranes should also include an appropriate impact factor. For example, ANSI Standard MH 27.1 “Specifications for Underhung Cranes and Monorail Systems” requires that for powered hoists the impact allowance shall be ½%

Table 9-1. USACE load combinations for design of tainter gates.
(EM1110-2-2702, JANUARY 1, 2000)

Loading Condition		USACE Load Combination							
Load Case		1			2		3	4	5
Description		Gate Closed			Two Hoists		One Hoist	Gate Jammed	Gate Fully Opened
Hydrostatic Loads									
Maximum possible	H_1	1.4			1.4				
10-year event	H_2		1.4			1.4	1.4	1.4	
Normal	H_3			1.2					
Dead load	D	1.2	1.2	1.2	1.2	1.2	1.2	1.2	k_d[a]
Mud weight	M	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6
Ice weight	C	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6
Ice impact	I		or k_1[b]			or k_1			
Machinery Loads									
Maximum machinery load	Q_1		1.2					or 1.2	
Machinery weight	Q_2	1.2	or 1.2						
Max downward load of hydraulic cylinder	Q_3							1.2	or 1.3
Side seal friction	F_s				1.4	1.4	1.4		
Trunnion Friction	F_t				1.0	1.0	1.0		
Earthquake	E			1.0					or 1.0
Wave	W_a		1.2			or 1.2			
Wind	W								1.3

[a] When *Q3* is considered, or when effects *W* or *E* oppose those of gravity, *C* and *M* should be equal to 0 and the load factor k_d is equal to 0.9.

[b] The *I* load factor k_1 shall be equal to 1.6 when considering ice load due to thermal expansion and 1.0 when considering impact of debris.

Source: Courtesy of USACE

of the rated load for each foot per minute with a minimum allowance of 15% and a maximum of 50%. The ASCE Standard 7 (Paragraph 4.9 in 7-10 Edition) specifies historic crane loads that have been traditionally used to successfully design crane support structures including:

- Additional vertical impact forces of 25% for monorail and cab operated cranes and 10% for powered pendant bridge cranes.
- Lateral force of 20%of the rated capacity of the crane and weight of the hoist and trolley.
- Longitudinal force of 10% of the maximum crane wheel load for supports of powered cranes.

Because gate hoists typically only operate intermittently and their seismic loads are much less than other transient loads it is commonly unnecessary to separately evaluate the gate operating system and mounting system for seismic loadings. But these may need to be investigated under special circumstances such as if the gate is permanently held in position by the operating system, a seismic load could cause failure of the gate, or the gate failure would cause a catastrophic event. Also the post earthquake effects on gate operator considerations such as communication systems and safety may need to be evaluated.

9.3 Evaluation criteria

Described below are the criteria chosen for evaluation of steel, concrete, wood, and cast iron gate structures. The intent is to provide guidelines for evaluating loads and capacities according to established codes and industry standards. An alternate approach would be to perform a risk-based analysis.

9.3.1 Steel gate evaluation criteria

Included in this section is a brief description of the strength, fatigue, fracture, and deflection criteria to be used in the evaluation of carbon and stainless steel gate structures. These criteria are applicable to steel components, welds, bolted joints, etc. that are being evaluated.

9.3.1.1 Steel gate strength evaluation criteria

To evaluate carbon and stainless steel gate structures for continued operation, it is necessary to define strength criteria, which will ensure continued safe functionality. Steel gate structures are composed of plate or shell type components and/or linear type members, such as beams and columns. A strength evaluation criteria needs to consistently address both all of components.

The American Institute of Steel Construction (AISC) Manual of Steel Construction is the most commonly accepted steel design technical guideline, and beginning with the 13th Edition does not recognize the historic allowable stress design method, but rather includes the two distinct methods; Load and Resistance Factor Design (LRFD) and Allowable Strength Design (ASD) methods. As discussed in the AISC Code commentary in Chapter B3 the prime drawback of the traditional ASD approach is that the safety factors were based solely on experience and the actual level of safety was never known.

Therefore, if an existing gate constructed of steel grades applicable to the AISC Code warrants an updated strength analysis, this guideline recommends that its competency should be determined using either the LRFD or Allowable Strength Approaches as presented in the latest AISC Code.

The LRFD provisions are based on a combination of probabilistic models of loads and resistance, calibration with previous AISC steel codes, and expert judgment based on comparative studies of representative structures. The ASD approach is based on the same controlling modes of failure and nominal strengths as LRFD. The AISC ASD safety factors were determined by calibration with the LRFD approach to assure similar levels of safety and reliability for a ratio of live-to-dead load of three based on a 1.2 dead and 1.6 live load factors. Because water control gates frequently have larger live-to-dead load ratios than three, using the ASD safety factors may not result in the same member safety and reliability as the LRFD approach.

The latest edition of ASCE/SEI 07 (Section 2.3 in 2010 Code) should be used to define the load factors. For example ASCE 07 uses 1.4 for a combination of dead (D) and fluid (F) loads with well defined pressures and defined heads. For Flood Loads (Fa) ASCE/SEI 07 applies Flood Load factors from 2.0 for high flood damage and coastal zones to 1.0 for non-coastal locations. Generally, the most significant loadings on gates are dead weight and hydrostatic water pressure loads, and a 1.4 load factor is appropriate. A 1.6 load factor is recommended for downpull, uplift, and hydrodynamic pressures that cannot be as well defined as hydrostatic pressures, yet can be more accurately defined compared to some flood loads.

If the gate structure being evaluated is subjected to less accurately definable dynamic loadings, or if it is difficult to inspect and maintain the gate structure on a routine basis, then consideration should be given to reductions in the AISC Code values as specified in the United States Corps of Engineers (USACE) Engineering Manual No. EM 1110-2-2105 “Hydraulic Steel Structures” (HSS) even though this Manual is based on the now superseded allowable stress steel design method

The combined primary bending and any membrane (mid-surface) stresses in flat plate members, such as a gate skinplate, shall conform to the normal AISC criteria. Secondary plate bending stresses induced into curved plates by the plate curvature is conventionally not considered in the analysis unless that member is being analyzed for fatigue or fracture.

A risk-based failure mode analysis would use a probabilistic comparison of the loads and resistance so the load, resistance, or safety factors would not be applied.

9.3.1.2 Steel material properties

For steel gates, material properties may be assumed as the historical material properties established at the time of fabrication. Note that any subsequent gate modifications will probably have incorporated steel that was available at the time of the change. Information on historic steel properties can be found in the two AISC publications: “Historic Record Dimensions and Properties” by Herbert Ferris, and “Design Guideline No. 15, AISC Rehabilitation and Retrofit Guide, A Reference for Historic Shapes and Specifications,” by Roger L. Brockenbrough.

Although minimum historic steel properties are commonly assumed in the evaluation of older steel gates, a more accurate understanding of the actual gate material properties is possible by testing the actual material. The most useful test is to determine the material yield and tensile testing in accordance with ASTM A-370. To obtain an accurate material representation, least three tests for each probable steel heat should be obtained. For example, steel plate and rolled shapes in a gate would have been rolled from different steel batches and probably have different values. Comparing the tested material values with the historic minimums can provide insight into appropriate values to use in a specific evaluation. If widely divergent testing values are obtained, then generally an increased number of tests needs to be performed to obtain statistically significant results that give the necessary confidence level in actual material properties. The value of numerous destructive tests needs to be carefully considered since they may impact the usability of the gate. There are other alternatives including metallurgical chemistry sampling that can be considered to estimate material properties.

9.3.1.3 Steel fatigue evaluation criteria

To address fatigue concerns in carbon and stainless steel gate structures, a loading history and corresponding stress ranges must be available. The AISC Code, Appendix 3, provides guidance in judging acceptability based on fatigue usage. Note that provisions of the AISC Code Appendix 3 are based on the unfactored service loads; no evaluation of fatigue resistance is required if the number of application cycles of live load is less than 20,000, or if the live load stress range is less than the threshold stress range, F_{TH} (see Table A-3.1 in the

AISC Code. Further guidance on evaluation of fatigue effects can be obtained from the Corps of Engineers Manual No. EM 1110-2-2105.

9.3.1.4 Steel gate flaw evaluation criteria

If flaws are present in either beam, plate, shell members, or welds in steel gate structures and the member or weld cannot be replaced economically, a fracture mechanics evaluation will indicate the critical crack geometry and size that will cause instability and result in member fracture. Fracture mechanics is a well known, proven methodology used to predict and prevent the occurrence of brittle fracture. A detailed discussion of this topic is beyond the scope of this guideline. Further guidance on flaw evaluations can be obtained fracture mechanics references such as from the Corps of Engineers Manual No. 1110-2-2105 and "Fracture and Fatigue Control in Structures" Second Edition by J. M. Barsom and S. T. Rolfe.

9.3.1.5 Steel deflection evaluation criteria

Although strength criteria have been previously defined, it is important that deflection criteria be considered for the functionality of steel gate structures. For example, a particular gate component may be sufficiently strong, but have excessively large deflections so that the gate cannot properly function. Typical examples are deflections that allow unacceptable leakage, that cause physical interferences, and that cause uneven member loading. Generic deflection criteria cannot be predetermined and requires consideration of specific gate geometries. However, one should be aware that such criteria may be important when performing an evaluation of a steel gate structure.

9.3.2 Reinforced concrete gate evaluation criteria

Included in this section is a brief description of the stress and deflection criteria to be used in evaluating reinforced concrete gate structures.

9.3.2.1 Reinforced concrete gate stress evaluation criteria

For evaluation of reinforced concrete gate structures, methods that consider both service loads and load factors should be used. The methods prescribed in ACI-318 and modified by ASCE in "Strength Design for Reinforced-Concrete Hydraulic Structures" include the use of the "hydraulic factor" (H_f), load combinations, and member capacities that should be used.

9.3.2.2 Concrete gate deflection evaluation criteria

Generally, deflection of concrete gates will not be a limiting consideration because concrete gate elements are brittle and need to be relatively stiff to prevent cracking. Although generic deflection criteria cannot be quantified one should be aware that deflection may be important when looking at areas requiring close fit-up such as seals and guides.

9.3.3 Wood evaluation criteria

Included in this section is a brief description of the stress and deflection criteria to be used in the evaluation of wood gate structures.

9.3.3.1 Wood stress evaluation criteria

The methods proposed by the American Forest and Paper Association (AF&PA) in document ANSI/AF&PA NDS-2005 or latest edition, "National Design Specification for Wood Construction," should be used for the evaluation of wood gate structures. Design values are specified in the supplement to the AF&PA document. However, the design values must be multiplied by adjustment factors, which take into account such things as loading duration, temperature, service conditions, moisture content, etc. For example, wooden gates obviously experience high moisture contents and the NDS code accounts for this phenomenon by reducing the wood allowable stress by a Wet Service Factor, labeled Cm. Similarly, a Load Duration Factor, CD, ranges from 0.9 for dead load to 1.6 for seismic effects, and 2.0 for impact loads.

The selection of the appropriate stress depends on identifying the type and grade of the wood used in the gate. If reliable documentation is not available the type of wood can be discerned by microscopic examination of a small sample(s) by a qualified forester. The wood grade is determined by visual inspection of the actual wood members, and the grading criteria is described in ASTM D245 (Establishing Structural Grades and Related Allowable Properties for Visually Graded Lumber). Further details on the visual grading of wood are available from the American Lumber Standards Committee, P.O. Box 210, Germantown, MD 20974.

9.3.3.2 Wood deflection evaluation criteria

Although stress criteria have been previously defined, it is important that deflection criteria be considered for the functionality of wood gate structures. For example, stresses may be low in a particular gate component, but deflections are of such a magnitude that the gate cannot properly function. Note that wood is very elastic and can continue to plastically deform under long-term loadings. Also, wood volume changes with different moisture contents. Although deflection criteria cannot be generalized, one should be aware that such criteria can be important when performing an evaluation of a wood gate structure.

9.3.4 Cast iron gate evaluation criteria

Included in this section is a brief description of the stress and deflection criteria to be used in the evaluation of cast iron gate structures.

9.3.4.1 Cast iron stress evaluation criteria

The methods proposed by the American Water Works Association (AWWA) should be used for the stress evaluation of cast iron gate structures. Specification for cast iron sluice gates are contained in ANSI/AWWA C560, "AWWA Standard for Cast-Iron Slide Gates." Pertinent load combinations are to be formed, appropriate stresses calculated, and comparisons made to allowable stress criteria. For cast iron gate structures, the allowable stress value equals the specified material minimum ultimate tensile strength divided by a factor-of-safety of five.

9.3.4.2 Cast iron deflection evaluation criteria

Although stress criteria have been previously defined, it is also important that deflection criteria be considered for the functionality of cast iron gate structures. Because cast iron is a brittle material, cast iron gates generally have a very stiff configuration. Therefore, excessive deflections generally are not a problem. Although generic deflection criteria cannot be quantified, one should be aware that such criteria can be important when looking at areas of close fit-up such as the seals, guides, and seating wedges.

9.3.5 Support structures

Generally, gate and operating system support structures are constructed of steel and/or concrete, and should meet the normal stress and deflection criteria of the AISC Steel Construction Manual and ACI Code 318 respectively. The exceptions are that items and equipment subjected to repeated mechanical loadings should be evaluated with respect to standard equipment specifications that typically have lower allowable stresses than the AISC building code. For example, spreader beams should meet requirements of ANSI/ASME

B30.20 “Below-the-Hook Lifting Devices,” and crane components should meet requirements of Crane Manufactures Association of America Inc. (CMMA) specifications such as No. 70, “Specifications for Top Running Bridge and Gantry Type Multiple Girder Electric Overhead Traveling Cranes.” Both of these documents have allowable stresses of approximately one-third the material (tensile or shear) yield stresses or one-fifth the material’s ultimate stresses.

9.4 Structural evaluation

The structural evaluation of a gate involves an evaluation to determine stresses and deflections of all structural members in a gate and its support structure. Although the evaluation methodology for existing gates should follow the latest codes, it should be acknowledged that older legacy gates were designed to previous codes, and professional judgment needs to be exercised to determine the safety or load factors appropriate for a particular gate. If over the service life of a gate, a member or connection is subjected to more than 20,000 load cycles then, as described in Appendix 3 of the AISC Manual, a fatigue evaluation of those gate members should be considered to determine the safe remaining service life of that member on the existing gate. A fracture toughness evaluation is generally performed only when an unrepairable flaw is found in a structure, and it is necessary to determine the ability of that member to safely resist fracture.

9.4.1 Establish the load path

The structural integrity of a hydraulic gate should be evaluated following all possible load paths within the gate. Understanding a load path means that the forces and moments are methodically followed through members and their connections from the point of load application to the point of final support.

For example, loads from water pressure are initially resisted by the skinplate, which in turn is supported by stiffeners and beams. End reactions of beams transmit load into supporting piers through vertical slides or wheels on most gates, or supporting arms, columns, and trunnions on a tainter gate. It is necessary to follow load paths from the water pressure through each component, including supporting members, connections, anchor bolts, slides, pins, and supporting piers to determine how critical each component is in the load path. By using this method, the “weak link” can be determined.

The quantified reactions in each member and connection for each load path are used to calculate the member loads, which are then compared to the component's structural capacity.

Other guidelines to consider during a structural evaluation include:

- The most attention should be focused on those structural members that resist the greatest loads. Typical examples are connection points to the operating system, anchor bolts, and radial gate arm columns.
- The most critical structural members are those that do not have redundancy. Failure of these members can lead to a catastrophic overall structural failure, since there are no alternate load paths where the reactions can redistribute. Critical members subjected to tensile reactions are considered fracture critical members.

9.4.2 Strength evaluation

9.4.2.1 General

As previously outlined, various criteria are used to evaluate hydraulic gate structures. The structural integrity of each member, connection, and fastener should be evaluated. Most hydraulic structures are subjected to a more stressful environment and more unpredictable loads than other steel structures. Therefore, more conservative criteria have been developed.

Engineering judgment should be used when selecting the criteria that will be used to assess condition of the gate. The following items should be considered:

- Type of gate
- Purpose of the gate
- Condition of the gate including cracks or corrosion
- Operating criteria and procedures
- Maintainability
- Access to inspection
- Assumptions used during analysis
- Consequences of gate failure.

9.4.2.2 Strength evaluation methodology

The general methodology of strength evaluation of an existing gate structure consists of the following steps:

1. **Determine actual configuration of the gate**. While existing gate documentation may be available, it is important to field verify its accuracy. Field changes during construction, or later undocumented gate alterations may not be represented on as-built drawings, and could significantly affect the gate's structural response.
2. **Determine condition of the gate**. The effect of gate deterioration such as corrosion should be considered. Disfiguration, misalignment, or absence of a member should be evaluated and incorporated into the analysis.
3. **Determine properties of materials**. If possible, the type of material should be confirmed from original drawings and/or specifications. If original drawings or specifications cannot be located, then an initial analysis can be made by using material characteristics typical for the era when the gate was designed and fabricated. The AISC Design Guidelines No. 15 contains generic historical material property information from several published sources. If project specific material property values are warranted because the material is suspicious or the applied loads approach or exceed the material's strength capacity, representative material samples can be taken from the gate to perform destructive material testing. The most common testing is pulling prepared tensile specimens to determine material yield and tensile stresses.

   Also, mechanical properties can be approximated in-situ by using a portable hardness tester to determine the material tensile strength. The material yield strength would then be estimated by factoring this ultimate strength (by typical yield to ultimate strength ratios).

   Since the steel material specifications before 1950 did not have carbon level limitations, weldability on older gates may be an evaluation concern. The chemical composition of an existing steel gate is typically determined by laboratory analysis of a gate grinding samples or a coupon specimen(s). Other methods include field chemical analysis by a portable optical emission spectrometer or X-ray fluorescence spectrometers.
4. **Determine loads on the gate**. The loads and load combinations applicable to a specific gate need to be quantified as previously discussed in this chapter.
5. **Determine gate and support structure reactions.** With the advent of advanced computer technology, computer modeling methods are the most efficient method to calculate stresses within complicated gate structures where three-dimensional effects are sometimes critical and require consideration. It

is very important that the validity of computer analysis be confirmed by comparing key results, such as a summation of support reactions, with hand calculations. Generally, linear elastic analysis is used to determine the stresses within the gate.

Hand calculations can provide suitable accuracy for simple geometries, and if properly prepared, will show conservative results. As previously discussed, all load paths should be methodically followed to determine loads for members of the structure. Many experienced practitioners prefer hand calculations to model simpler gates since hand calculations can give a better understanding of the gate's load path and response. In fact, older gates were designed entirely two dimensionally, and were often constructed or detailed with partial or full moment connections.

6. **Strength evaluation**. The applied reactions of members and fasteners should be compared against load capacity for bending, tension, compression, shear, and combined conditions. Since many assumptions and unknowns are associated with stress levels, stresses in gate members designed by allowable stress methods are compared to allowable stress values that have been reduced from the minimum material properties by safety factors. Similarly, for members designed by load factor methods, the uncertainty is accounted for by comparing the factored load with the member capacity reduced by a service factor.

9.4.2.3 Components

Major components of a gate that need to be structurally evaluated include:

- Water barrier (skinplate)
- Skinplate stiffeners, which consist of horizontal and vertical beams and/or framing and truss structure
- Supporting components such as radial arm columns and bracing
- Wheels or rollers
- Tracks or guides
- Trunnions
- Anchorage such as girders, anchor bars, piers, etc.
- Member connections
- Attachment points.

9.4.3 Fatigue evaluation

Fatigue is the process of formation and growth of a crack due to cyclic loading. It is a progressive failure that depends on the number of cycles of loading, the range of load stress, and the discontinuity or flaw of an element. The AISC specification indicates there will be no fatigue effect for fewer than 20,000 cycles in steel structures. Due to the low number of load cycles experienced by most gates during their life, fatigue is generally not a concern.

Gates subjected to dynamic loading as a result of flow-induced vibration may result in fatigue type cracking or failure, and either the gate should be modified or the operation causing vibration avoided. Operation monitoring should be completed at different operational modes to determine if vibration is a consideration. It is difficult to analytically determine the load magnitudes and number of cycles from flow-induced vibration. Therefore, one approach to mitigating fatigue cracking in existing gates where a quantitative fatigue analysis is not possible is to modify the stress concentration details of gate features that display fatigue cracking. In this case, the choice of details shall be such to minimize future fatigue damage. Another approach is to field measure the actual stresses on a problem gate by applying strain gages to the gate, and evaluating the stresses calculated from the measured strains.

The fatigue life of gate members and connections can be evaluated as outlined in Appendix 3 of the AISC Specifications accompanying the 13th Edition of the Manual of Steel Construction. Typically an existing gate fatigue life evaluation would include a detailed gate inspection focusing on fatigue prone areas such as welds and member discontinuities.

9.4.4 Fracture toughness evaluation

A fracture toughness evaluation on a gate component is performed when there is a specific concern that discontinuities in the component or connection in an existing gate may lead to the sudden growth of a crack, which would cause failure. Although typically members with fractures such as cracks are either replaced or repaired, a fracture analysis may be used to determine the threshold acceptable fracture if repair or replacement is uneconomical or impractical to implement. Cracks also frequently initiate at weld discontinuities, and weld cracking is typically repaired by removing the cracked part of the weld (grinding or air arcing) and replacing with new weld conforming to approved welding procedures. A more detailed assessment should be performed where cracks have been repaired multiple times.

Fracture is governed by nominal stress level, material toughness, and geometry of an existing crack or flaw. The most critical members subject to fracture are defined as fracture critical members. These are members and/or connections that are subjected to tensile stresses and the failure of a tensile member (component) would cause catastrophic failure or inoperability of an entire structure.

The first step in a fracture analysis of a critical member or connection is to calculate the maximum possible tensile stress in the member being analyzed, which involves determining maximum stress concentration. Stress concentrations typically form at geometric discontinuities or changes in cross section. The maximum stress is determined by multiplying the nominal member stress (determined from a general strength analysis) by a stress concentration factor that depends on the geometry of the member being analyzed and the type of applied load. One useful reference for hand calculations is *Peterson's Stress Concentration Factors* by Walter and Deborah Pilkey. Another analytical method is to prepare a detailed local finite element model of the discontinuity area with the loads imported from the output of a more global finite element model of the entire structure.

The second step is to determine the size and shape of discontinuities (e.g., cracks, voids, porosity) in the member or connection being evaluated. This may already have been determined at least in part, since a fracture analysis is typically conducted on an existing gate only after an unrepairable discontinuity has been located in a critical gate component. The presence of a noticeable discontinuity usually warrants a thorough Non-Destructive Testing (NDT) inspection (Ultrasonic Testing [UT] for subsurface and Magnetic Particle Testing [MT] for surface defects) of relevant gate components.

The maximum stresses, size, and types of flaws are then compared with the actual condition of the component to determine if the component is in danger of brittle failure. Components with flaws and stress levels high enough to have a brittle failure need to either have the discontinuity repaired, the component replaced, or the stress decreased to an acceptable level.

9.4.5 Deflection evaluation

Deflection of a gate and its components should be evaluated based on the gate type and details of seals and support members. Deformation rather than stress is sometimes the criterion of a satisfactory design, although there is no single scale by which the limit of tolerable deflection can be defined. An allowable deflection will be dictated by the amount of deformation considered tolerable relative to potential seal leakage or increased friction as a result of deformation. Also, gate deflections could possibly be a problem on gates with particularly tight guide clearances.

Special attention should be given to gates constructed of high strength steel that may have sufficient strength, but lack rigidity and could experience excessive deflections.

9.4.6 Connections

The member connections need to be capable of transferring required forces and have the required stiffness to satisfy assumptions used in design or analysis. The most typical cause of failure for ductile structures (e.g., steel) is connection failure, where stress concentration, eccentricity, restraint, and fatigue need to be considered. Fasteners including welds, bolts, and rivets should be evaluated. A useful reference in evaluating connection strength of bolted and welded connections is the AISC Steel Construction Manual. Older gates typically have riveted connections. Riveted and bolted connections should be analyzed according to Kulak et al. (2001). While the loss of rivet head cross section may not decrease a rivet's shear resistance to loads perpendicular to the rivet shank, it may allow the connection to disengage if the heads are needed to resist plate reactions that are parallel to the rivet shank.

9.4.7 Anchorages and anchor bolts

The gate anchorage is a significant component of the overall stability of the gate. Anchorage failure could result in complete loss of a gate. In some cases, anchorage is set between two adjacent gates and unbalanced loads need to be evaluated. Post tensioned anchorage can be incorporated into the design of gates and is susceptible to corrosion. Because there currently is no conclusive methodology to determine the in-situ condition of post tensioned anchors, careful visual inspection is required to determine if corrosion is present. The remaining capacity of a post tension anchor can sometimes be tested by performing a lift off test.

The strength of the concrete anchorage needs consideration and should be compared against the appropriate stress criteria. Signs of distress near the trunnion anchorage or within concrete piers, such as cracking and/or spalling, could indicate unacceptable anchorage reactions. On older gates, the analysis of the concrete and reinforcing may not meet current requirements of the America Concrete Institute (ACI code 318 Appendix D).

Concrete anchorages and anchor bolts need to be able to transfer the required forces and have the required stiffness to satisfy the assumptions used in design or analysis. There have been changes by ACI concerning the requirements for the design of anchorages and anchor bolts and Appendix D of the ACI 318 Code provides useful information. These changes have resulted from less than satisfactory performance of critical anchorages and anchor bolts. Historically designed anchorages and anchor bolts may not meet current ACI code requirements.

Another important evaluation related to anchorages is the weak axis strength and stability of support piers to transverse forces, such as seismic loads.

9.5 Operating system evaluation

A gate operating system can be a totally custom designed and built system; a custom designed system using various standard manufactured components such as gears, brakes, shafts, bearings, and pumps, motors, limit switches; or a totally proprietary designed and manufactured system such as a crane, hydraulic cylinders with power unit, or actuator with screw stems. To comprehensively address the almost limitless variety of gate operating and control systems, this guideline categorizes operating system evaluations as either component or system evaluations.

9.5.1 Component evaluation

A component evaluation is when the fitness for use and service life of a particular item is being evaluated. This is generally the result of some observed deterioration of a particular component from its new condition. If component deterioration is not judged to seriously compromise gate operation, the first option is to accept the deterioration and modify maintenance and/or operating procedures to prevent further deterioration. A second option is to repair the deterioration and continue using the component, and a third option is to replace the component.

The normal criteria for evaluating a mechanical or electrical component are its “as new” condition. Chapter 7 discuss particular characteristics for various mechanical and electrical system components that should be observed, and these observations should be compared to the as new condition of the component.

The appropriate scope and detail of component evaluation will depend on various factors such as the importance of the component to gate operation and cost to repair or replace. For example, for standard manufactured components such as bearings, gears, motors, etc. that have already provided a long service life without premature deterioration, the most technically prudent and cost effective alternative is typically to replace the component in kind with only an informal evaluation. Conversely, if the component is very unique and costly to replace (and particularly if it is critical to the gate's operation), a detailed mechanical evaluation may be judicious. For example, the appearance of gate shaft cracking on a large tainter gate hoisting drum would warrant a detailed investigation. In general, a detailed component evaluation should include determination of:

- the extent of component deterioration/damage
- the cause of component deterioration/damage
- the effect of deterioration on component performance, safety, and reliability
- a repair procedure and/or replacement specification that addresses the root cause revealed by the evaluation.

The reoccurrence of repeated premature component deterioration probably warrants a detailed evaluation to determine the root cause, which may necessitate reviewing the entire system.

9.5.2 Operating system evaluation

An operating system evaluation is when all components are reviewed to determine the condition of the entire gate mechanical or electrical system. This type of evaluation requires a global understanding of the entire gate operating system, which involves knowing the characteristics of each individual component, their compatibility, and how the system responds to all situations.

The general methodology for a system evaluation is to determine:

- All the gate hoisting requirements such as lifting loads, speeds, control requirements (e.g., manual, remote, or automatic operation), etc.
- The compatibility of system components to hoisting requirements. For example, hoist power train components must have sufficient strength and capacity. The most common approach is to systematically confirm strength

by following gate lifting reactions through each hoist component from the connection to the gate to the hoist anchorage and support. In addition to strength, each component must have a properly mated connection to its adjacent component. An electrical system would follow a similar methodical approach to confirm the compatibility and performance of each system component from the initial sensing unit through the control solenoids to the activation signal source.

- The ability of a system to correctly respond to conditions that the operating system may experience should be evaluated. Examples include: temporary methods of hoist operation during emergency conditions such as loss of primary power, backup or failsafe guards in the event of a travel limit switch malfunction, and ability to safely respond to overload conditions such as increased friction or gate jamming.

9.6 Functional evaluation

9.6.1 General

The functionality of gates should be routinely assessed by operating staff every time a gate is partially or fully exercised. When proper gate operation is critical for public safety or environmental reasons, a documented functional evaluation of gate operation or test operation should consist of normal loads and, if practical (and to the extent possible), extreme operating loads.

Written records of functional evaluations should be maintained for several reasons. They provide a long-term history of gate operations compared to original design intent, they can be used for trending predictive maintenance requirements, and they can be used in conjunction with gage flow records for computer modeling of flood control release times and wave travel times within a flood basin.

9.6.2 Reliable operation

The importance of reliable operation of a gate and its control system may depend on several variables. These variables include cycle time to open and close, number of gates available for the intended purpose, and importance of discharge requirements for power, irrigation, flood control, water quality, etc. Owners, operators, and regulators must consider gate usage and reliability relative to the intended purpose of the gate.

9.6.2.1 Cycle times

Cycle times are important when the purpose of gate operation is flow control based on critical timing relative to control of a hydroelectric turbine or a pumping station system. Also, cycle times are important to opening spillway gates for flood control, where each gate does not have a dedicated hoist.

Hydroelectric turbines generally have specific flow control needs for startup and shutdown functions: both controlled and uncontrolled. While turbine components such as turbine blades and wicket gates generally control flows during these instances, headgates are the typical back-up means for turbine shutdown. Certain types of turbines actually rely on the headgate system itself as a means of start-up and shut-down. Vertical lift gates are generally used in this application with control times for gate actuation closely tied to turbine manufacturer requirements for runaway speed, duration, and shaft specific speed requirements. For gates performing this purpose, cycle times of gate operation should be compared annually to the turbine manufacturer's requirements.

Operation of turbines and pumps located on aqueduct and canal systems can affect critical water levels during shutdown. When a turbine or pump shuts down, it causes a transient wave with a temporary increase in water level. Some canals have stringent water level control requirements due to freeboard, structural safety considerations for canal walls, or public safety. In these instances, hinged crest gates or inflatable bladders have been installed to mitigate the change in water level. The control system for gate operation is connected to the turbine or pump, and when shutdown occurs, a signal is sent to operate gate to pre-determined settings to decrease or eliminate the surge wave. In this example, cycle times for gate operation are critical to properly mitigate water level surge, and gate operation must be closely matched to equipment shutdown rates. Timing intervals should be verified and calibrated annually.

9.6.2.2 Multiple gate configurations

For facilities with multiple gates, functional testing of individual gates may be alternated during successive years. This may be necessary for spillways with large radial gates and sites where conservation of water for irrigation or environmental reasons is desired. Typically, multiple gate configurations provide a highly redundant level of flow discharge capacity in comparison to normal discharge requirements. As such, it is generally not necessary to functionally test every gate each year. Shared hoists are especially critical and need to be tested on different gates. Size and use of the project and the number of gates should dictate the appropriate program for functional tests.

Where proper gate operation is critical for flood control purposes or dam safety (such as to prevent earthen dike overtopping), each gate should be full-travel test-operated on at least a 5-year recurring basis. This also helps to ensure that debris and sediment build-up on the impoundment side of the gate does not become troublesome for proper gate operation. Longer inspection intervals may be adequate where operation is not critical, such as designs that also include an ungated emergency overflow. Gate operating systems should still be inspected and tested on an annual basis to ensure their functionality.

9.6.2.3 Requirements-based discharges

Functional reliability takes many forms depending on the end-user. While a day, week, or month of outage time for a gate may be acceptable for power or water quality usage, typically it would not be acceptable for meeting irrigation or flood control demands. Therefore, the end-user or entity most impacted by the reliable operation of a gate system must be considered when determining the acceptable reliability requirements. Typically, every gate with a mechanical operating system should have provisions for emergency operation. Commonly a back-up manual handwheel (frequently with a center nut suitable for wheel rotation by a portable drill) is provided as a temporary means of gate operation in the event of a loss of power. Another means to provide backup gate operation is a stand-by engine-operated generator. Hydraulic power units (HPU) can have accumulator tanks or hand pumps to provide for emergency gate operation. Other provisions that can be used to increase gate functional reliability include maintaining an adequate supply of important spare parts on-site for quick and easy access for repairs, storage batteries for temporary power, and a duplicate HPU or the ability to quickly tie into an auxiliary or station HPU.

9.6.3 Diagnosing abnormal operating characteristics

9.6.3.1 General

Abnormal operating conditions can occur at any time. In addition to issues with the operating system itself, they may be induced by abnormally large applied loads and short or long-term wear. Typical characteristics of abnormal operation include unusual noises, vibration, uneven gate movement, binding, etc. This section identifies some common gate abnormalities and their causes.

9.6.3.2 Unusual noise

Noises during gate operation should be isolated to either the gate or the operating system. If emanating from the gate, two typical causes are debris or foreign materials caught between the gate bearing surfaces and guides, or failure of components such as wheels, tracks, or bearing surfaces. Partial opening and closing of a gate followed by either an upstream or downstream inspection may determine the root cause of noise. While debris lodged in the guides can cause leakage problems, it generally does not jeopardize structural competency. Conversely, the failure of an important load-bearing element, such as a bearing on a wheel-mounted gate can have severe consequences and should be addressed as soon as possible. Great care should be given to operating gates that could be experiencing bearing problems. Seized bearings can increase internal stresses and reduce factors of safety beyond acceptable limits. Also, noises may be attributable to vibration or binding of the gate, which is addressed subsequently in this chapter.

Noises associated with the operating system should be isolated to the apparent area and addressed depending on actual conditions encountered. Common noises associated with an operating system would be grinding or metal-to-metal sounds, which could be associated with bearings, stem misalignment, connector bushings, or gear misalignment. Grinding noises associated with subsequent banging noises can be associated with cable or chain slipping, improper lubrication, motor noises, etc. Generally, operating system noises should be corrected immediately.

9.6.3.3 Vibration

Vibration experienced in gate operation is of two types, either hydraulically or mechanically induced. A vibration resonance that imparts a consistent harmonic amplitude has also been known to cause structural failures of adjacent components.

Flow-induced vibration for vertical lift gates typically occurs when a gate is initially cracked open or just before seating fully closed. Flow-induced vibration is the result of differential pressure and turbulent flow conditions under the gate. This condition is most commonly experienced by various types of gates and is usually a temporary condition that is eliminated with increased opening or fully closure of a gate. Flow beneath the bottom profile of the gate induces unstable flow conditions and/or separation resulting in fluctuating pressures. It is not recommended that a gate be left in any open position that imparts vibration. Vibration has been known to cause erosion and cavitation of surrounding surfaces and to prematurely wear other gate components such as seals, bushings, and bearings. Also, vibration has contributed to fatigue and breakage of welds.

Flow-induced vibration for overflow gates such as hinged crest gates and inflatable rubber dams is caused by an unstable vacuum condition under the flow nappe. Common techniques to relieve this vacuum condition under the flow nappe are flow splitters or tabs to break the surface of the spill, or abutment vents to the underside of the spill. Damaged or missing flow splitters should be repaired, and blocked air vents should be opened.

Depending on the downstream profile of the spillway, the air cavity beneath a flow nappe becomes choked off with gate lowering. If back-water beneath the gates can rise to enter air vents, violent surging will occur in the air vents resulting in corresponding gate vibration.

Mechanically induced vibration is commonly caused by either improper component alignment of the lifting mechanism or loose connections. Either of these conditions is undesirable and should be corrected as soon as possible.

9.6.3.4 Uneven movement

Operating motion is a factor for many components depending on the type of gate and operating system. For gates with two or more lifting elements such as dual hydraulic cylinders, wire rope hoists, and threaded stems, synchronization of the operating system is extremely important. For instance, if two hydraulic cylinders are used, unequal rod travel can result in gate binding and significantly increase system operating pressures and the potential for component failure. If system overpressure protection is inadequate, a failure could be catastrophic.

Also, unequal lifting forces on multiple lifting element hoists can impact the structural integrity of component members. Therefore, it is important that during functional test-operation, the hoist synchronization be confirmed and adjustments implemented to maintain uniform lifting of the gate.

On a single lifting of element hoists, uneven motion will lead to a “jerky” operation with erratic gate travel. In a worst-case scenario, erratic gate travel can cause component failure. In a typical case scenario, it can lead to gate binding. The most common cause for erratic movement is gate binding and guide interference. Typically, this is more of a problem with slide gates than with roller type gates.

9.6.3.5 Binding

Gates bind for a number of reasons, but unless caused by lodged debris, the root cause is generally misalignment. Gates, lifting components, and actuators must be in correct alignment for the system to work properly. Typical signs of misalignment would include abnormal wear of rod seals (on hydraulic cylinders), wire rope scarring or fraying (on wire rope hoists), broken or cracked teeth (on rack-and-pinion hoists) and worn, broken, or cracked stem threads on screw hoists. The most typical cause for misalignment of operating system components is loose anchors bolts or support movement.

For multiple lifting element hoists, a common cause of binding is uneven gate lift due to poorly synchronized lifting elements. In this instance, the gate will rack between guides and try to wedge itself in place. In such instances, the gate may need to be forced downward to un-wedge and re-seat properly within the guides. Gate binding in the upstream/downstream direction is typically caused by improper operating system alignment or debris either wedged under gate or in gate guides.

Another cause of gate binding is a decrease in span between gate bay walls or gate guides due to pier expansion caused by concrete growth such as AAR or AASR. The presence of AASR can usually be visually identified by the presence of concrete cracking and growth rings around concrete aggregate. It can be definitely confirmed by a concrete petrographic analysis.

9.6.4 Seals and leakage

Chapter 2 described various types of gate seals; the following paragraphs discuss seal evaluation.

Types of seals typically depend on the age of gates and technology used when the gates were built. Older gates typically relied on wooden or metal seals. Except for high-head gates, most gates with newer technology use some form of rubber or UHMW material seal. The rubber typically mates and seals against a bronze or stainless steel sealing surface to prevent leakage from guide surface pitting. In evaluating seals, the two important factors to consider are the amount of leakage and seal deterioration or damage.

9.6.4.1 Seal leakage

The amount of leakage past the sealing surfaces should be assessed to determine whether or not seal replacement is appropriate. The three most prevalent reasons for excessive leakage are seal or sealing surface deterioration due to age, damage to the seal or sealing surface due to debris, ice, or erosion; and lack of seal pressures due to incorrect installation or movement. "Seating Head" refers to gate/guide arrangements where the water pressure pushes the gate body (i.e., disk) against the guides and sealing surfaces, while "Unseating Head" means that the water pressure pushes the gate body away from the guides and sealing surfaces.

A traditional criterion for acceptable levels of leakage for sluice gates with seating head seals as given in the *AWWA Standard for Cast Iron Sluice Gates* ANSI/AWWA C560 is 0.1 gal per min per lineal foot of sealing surface. For unseating heads up to 20 ft, the maximum acceptable leakage rate is 0.2 gpm per lineal foot of sealing surface. Above 20 ft of unseating head, the maximum allowable leakage rate (in gallons per minute per foot of sealing perimeter) is 0.1 to 0.005 times the unseating head (in feet). Variations to this standard are made based of the intended usage of the gate. For instance, sluice gates constantly exposed to upstream head and extreme cold environments may need to have zero seal leakage to prevent winter icing problems.

In assessing the leakage past flexible rubber seal arrangements, inspections should be made in both warm and cold weather, if applicable, observing areas of leakage to determine the cause. Leakage could be caused by damaged or deteriorated seals, improper seal compression, or gaps at seal splice joints (especially at the corners). Damaged or deteriorated seals are discussed below. Furthermore, since the same durometer of seal hardness is often used for an entire side seal length, it is not uncommon for seals to leak more near the top, particularly during winter months when there is insufficient pressure to seat more rigid seals.

Leakage through seal splice joints generally occurs due to either seal aging or improper splicing techniques. Due to ultraviolet or ozone degradation, rubber seals tend to become more brittle with years of service and exposure to temperature fluctuations, which can lead to contraction at seal ends or separation of splice joints. Replacement of the seals is generally the best solution when this occurs. Sometimes seal replacement may not be possible due to time, expense, or gate location. In this case, effective repairs can be made by the installation of caulking compounds or vulcanizing additional rubber materials into the splice joints using an electrically heated splicing mold.

Rubber seal splice failures commonly occur at field splices (vs. factory splices). Generally, this is due to less than ideal conditions when splices are made. Factory vulcanized splices will rarely fail. Field splices can be made two ways: by field vulcanizing and by use of a non-water-based cement. Failures of field-vulcanized splices are generally attributed to either improper preparation techniques or insufficient temperature in the vulcanizing process. Failures of field-cemented splices can occur due to the use of incorrect cementitious materials, but is usually the result of improper preparation techniques.

If it is not practical to immediately repair gate seals, it is a good practice to photograph leakage areas for comparison during the next inspection or dewatering. Note that leakage under high head is more likely to cause further erosion damage to the sealing surfaces. Repair cost may escalate quickly.

9.6.4.2 Seal deterioration or damage

An evaluation of both material deterioration and physical damage should be made for sealing surfaces. The evaluation of both the seal strip or member and the mating seal surface on the guides should include:

- The brittleness of rubber seal strips needs to be assessed to evaluate their ability to seal and their propensity for tearing damage. Deteriorated rubber should be replaced. The ripping or tearing of undeteriorated seals that has been caused by excessive friction between seal strips and seal seats can be corrected by using seals with a fluorocarbon sheath on the seal bulb.
- The structural condition of some butt splice joints, retaining bars, and connecting bolts. Components with excessive corrosion or loss of material should be replaced.
- The condition of the gate guides and/or frames is sometimes overlooked, but should be examined. Because guides/frames are generally submerged, the inspection is routinely performed by divers (documenting with audio comments and video), and increasingly with a Remote Operating Vehicle (ROV).

- Seal seating surfaces of gate guides or frames that mate with rubber seals should be free of surface deterioration such as pitting, erosion, and gouges. Seal seat members should be level, plumb, and/or in common plane; and aligned with the gate seal travel path.

Major guide or frame repairs typically require stoplog or a temporary cofferdam installation. Minor guide repairs such as surface pitting have been successfully smoothed in the past by divers applying proprietary compounds such as manufactured by Belzoma.

While seals that experience extreme temperature swings and significant gate usage may show signs of deterioration after as little as 8 to 10 years of service, typical rubber seal life should be in the 25- to 35-year range.

9.7 Potential failure mode analysis

9.7.1 Description of PFM process

Beginning in 2003, the Federal Energy Regulatory Commission (FERC) implemented a new Dam Safety Performance Monitoring Program (DSPMP). DSPMP requirements are included in Chapter 14 of FERC's Engineering Guidelines dated July 1, 2005. A key requirement of the DSPMP is to conduct a Potential Failure Modes Analysis (PFMA) and prepare a PFMA report. The PFMA is intended to broaden the scope of traditional dam safety evaluations. A Core Team consisting of the FERC inspector, Independent Consultants, Owner's representatives, and PFMA Facilitator participate in a workshop to identify potential failure modes under hydrologic, seismic, static, and operating conditions. The results of the PFMA process are used by the Independent Consultants to guide the Part 12 safety inspections, evaluate monitoring and surveillance programs, and recommend risk reduction measures, if needed.

During the PFMA workshop, participants brainstorm potential failure modes (PFMs) associated with hydrologic, seismic, static, and operating conditions. For each PFM, the group discusses factors and conditions that are considered favorable (i.e., that make the failure scenario less likely to occur) or adverse (i.e., that make the failure more likely to occur). Possible risk reduction measures are identified for certain PFMs. The team members then rate each PFM according to the FERC criteria listed in Table 9-2 based on information available, adverse and favorable conditions, and likelihood that the PFM could lead to failure of the dam, or to uncontrolled release of the reservoir water. The PFMA is a process that has typically been applied to spillway gates because of their importance to dam safety but the process could also be applied to gates at other outlets such as sluices, penstocks, conduits, and bypass tunnels.

9.7.2 Typical potential failure modes for spillway gates

This section includes some typical examples of PFMs identified for spillway gates and is not intended to be comprehensive. PFMs may be documented in many ways. Six PFM examples in two formats are included in Appendix E.

Example 1 – A summer thunderstorm event, with spillway radial gates closed and flashboards installed, leads to overtopping of an earthen dam, erosion, and dam failure.

Potential risk reduction measures – Develop spillway operating procedures to respond to thunderstorm events when reservoir water level could change quickly.

Table 9-2. Potential failure mode categories.

Category	Description
I Highlighted Potential Failure Modes	Those potential failure modes of greatest significance considering need for awareness, potential for occurrence, magnitude of consequence and likelihood of adverse response (physical possibility is evident, fundamental flaw or weakness is identified and conditions and events leading to failure seemed reasonable and credible) are highlighted.
II Potential Failure Modes Considered, but not Highlighted	These are judged to be of lesser significance and likelihood. Note that even though these potential failure modes are considered less significant than Category I, they are also described and included with reasons for and against the occurrence of the potential failure mode. The reason for the lesser significance is noted and summarized in the documentation report or notes.
III More Information or Analyses Needed to Classify	These potential failure modes to some degree lacked information to allow a confident judgment of significance and thus a dam safety investigative action or analyses can be recommended. Because action is required before resolution, the need for this action may also be highlighted.
IV Potential Failure Mode Ruled Out	Potential failure modes may be ruled out because the physical possibility does not exist, information came to light that eliminated the concern that had generated the development of the potential failure mode, or the potential failure mode is clearly so remote as to be non-credible or not reasonable to postulate.

Example 2 - Debris and/or ice partially clog spillway gate openings, causing reduction in spillway capacity and dam overtopping.

Potential risk reduction measures - Annually remove large debris from reservoir rim to reduce the possibility of high water transporting material into the spillway gate bays.

Example 3 - Spillway gates on flashy watershed requires local operation. Local, prolonged thunderstorm with lightening prevents operating personnel from gaining safe access to spillway gate controls, leading to overtopping of the dam.

Potential risk reduction measures – Consider installation of remote gate controls located off the dam to allow for safe gate operation during all weather conditions.

Example 4 – Increase in trunnion pin friction of spillway radial gate allows radial arm columns to become overstressed and buckle during operation.

Potential risk reduction measures – Develop plans for strengthening the radial gate arm columns to allow higher trunnion pin friction should be implemented.

Example 5 –Automated drum gate controls malfunction causing one or both drum gates to drop uncontrollably. The potential adverse consequence of this failure mode is that the river water level would rise unexpectedly. Anyone near or in the river downstream of the Dam would be at risk of injury or drowning.

Potential risk reduction measures – Many aspects of drum gate control and communication systems, including lake level, are being upgraded. Work began in 2005 and was completed in 2007. Until the reliability of the upgraded system is proven, continue practice of providing additional on-site personnel during critical operations and when storm events are forecasted.

Example 6 - Automated control system fails due to debris accumulation, causing an unscheduled lowering of drum gates to fully open position, resulting in downstream flooding.

Potential risk reduction measures – Upgrade the control system to avoid uncontrolled operation and have additional staff on site when storms are forecasted and debris accumulation can be expected.

9.7.3 Typical risk reduction measures

Based on the PFMA experiences over the last several years some typical measures that can be useful to improve reliability and mitigate risk of spillway gate malfunction may include:

- Motorize and automate spillway radial gates so they can be operated remotely, reducing response time.
- Provide redundant gate position indication for remotely operated gates.
- Train additional and backup staff to operate gates
- Post operation staff at dam if spill is forecast
- Provide an emergency engine generator at the dam as backup power source for gate operation and/or provide other backup methods of practical non-power emergency operation.
- Periodically test-operate gates full-travel open and closed
- Verify full-open dimension of gates
- Develop written procedure for gate operation
- Manage debris on the reservoir

While many of these measures are good operating practice, the reduction of risk is difficult to assess without a more detailed risk analysis. Depending on the complexity and details of the failure modes and the relevant risk reduction measures, further risk analysis may be appropriate.

Appendix A: Inspection Checklists[1]

Included in this appendix are inspection checklists that can be used during a particular type of inspection. These checklists are for example only and will need to be modified to fit the particular gates that are to be inspected.

The checklists included in this appendix are the informal inspection, intermediate inspection, periodic inspection, close-up inspection, and emergency generator.

[1] These inspection forms were adapted from TVA inspection forms.

MONTHLY INFORMAL SITE PERSONNEL INSPECTION CHECKLIST

STRUCTURAL/MECHANICAL COMPONENTS
SPILLWAY GATES AND MACHINERY

_______________ **PROJECT**
INSPECTED BY: ____________________________ HW ELEV.: ______
PLANT MAINTENANCE MANAGER: __________________________
DATE OF INSPECTION: ________________________________

S–SATISFACTORY, U–UNSATISFACTORY (DESCRIBE UNDER COMMENTS)

NOTE: FAX COMPLETED FORM TO THE ENGINEERING STAFF AT

GATE STRUCTURAL FEATURES
STRUCTURAL STEEL
____ MEMBER DISTORTION, DAMAGE
____ GRATING CONDITION
____ VEGETATION, DEBRIS
____ EXCESSIVE CORROSION
GATE SEALS
____ DAMAGE
____ EXCESSIVE LEAKS

HOIST MECHANICAL FEATURES
HOIST WORM REDUCER (QTY ___)
____ OIL LEVEL
____ OIL LEAKS
____ DRAIN CONDENSATION
PINION GEAR AND GEAR CASES (QTY ___)
____ OIL COATING ON GEARS
____ DRAIN CONDENSATION
BRAKE (THRUSTER) (QTY ___)
____ PROPER OPERATION
____ SHOE CONDITION
____ DRUM/DISC CONDITION
MACHINE BEARINGS
____ LUBRICATION
LIFTING CHAINS/WIRE ROPES
____ DAMAGE
____ BROKEN LINKS/WIRES
GATE TRUNNIONS (QTY ___)
____ LUBRICATION

GATE TEST OPERATION (6-IN. OPEN)
____ UNUSUAL BINDING, VIBRATION
____ OPERATIONAL PROBLEMS
____ TEST SLACK LIMIT SWITCH
____ POSITION INDICATOR

GATE OPERABILITY TESTING
RECORD ON THE TABLE BELOW GATES THAT WERE TEST-OPERATED FOR A SPILL EVENT SINCE THE LAST INFORMAL INSPECTION.

1	2	3	4	5	6	7	8	9	10

INSPECTION COMMENTS (DESCRIBE UNSATISFACTORY CONDITIONS):
____
____
____

INSTRUCTIONS:
1 ALL FEATURES LISTED ABOVE ARE TO BE INSPECTED MONTHLY AND AFTER AN UNUSUAL EVENT LIKE SEVERE FLOODING, HIGH HEADWATER, OR EARTHQUAKE.
2 IMMEDIATELY REPORT SERIOUS DAM SAFETY PROBLEMS TO THE CONTROL ROOM OPERATOR, THE MAINTENANCE MANAGER AND THE ENGINEERING STAFF (_______________).

INTERMEDIATE ENGINEERING INSPECTION CHECKLIST
STRUCTURAL/MECHANICAL COMPONENTS
SPILLWAY GATES AND MACHINERY

_______________ PROJECT

INSPECTED BY: ____________________________ HW ELEV.: ______
DATE OF INSPECTION: ________________________________

S–SATISFACTORY, U–UNSATISFACTORY (DESCRIBE UNDER COMMENTS)

GATE STRUCTURAL FEATURES
STRUCTURAL STEEL
____ MEMBER DISTORTION, DAMAGE
____ COATING CONDITION
____ VEGETATION, DEBRIS
____ EXCESSIVE CORROSION
SPILLWAY GATE SEALS
____ DAMAGE, WEAR
____ EXCESSIVE LEAKS

HOIST MECHANICAL FEATURES
HOIST WORM REDUCER (QTY ___)
____ OIL LEVEL
____ OIL LEAKS
PINION GEAR AND GEAR CASES (QTY ___)
____ OIL COATING ON GEARS
____ DRAIN CONDENSATION

BRAKE THRUSTOR (QTY. ___)
MACHINE BEARINGS
____ LUBRICATION
LIFTING CHAINS/WIRE ROPE
____ DAMAGE
____ WEAR
____ BROKEN LINKS, WIRES
____ MIC WIRES TO CONFIRM DIA.
GATE GATE TRUNNIONS (QTY ___)
____ LUBRICATION

GATE TEST OPERATION (1 FT OPEN)
____ UNUSUAL BINDING, VIBRATION
____ TEST SLACK LIMIT SWITCH
____ POSITION INDICATOR
____RECORD HOIST MOTOR VOLTAGE, AMPERAGE

GATE OPERABILITY TESTING
RECORD ON TABLE BELOW GATES THAT WERE TEST-OPERATED AND TO WHAT LEVEL (SEE NOTE 1).

1	2	3	4	5	6	7	8	9	10

INSPECTION COMMENTS (DESCRIBE UNSATISFACTORY CONDITIONS):
____
____
____
____
____

INSTRUCTIONS:
1. TEST-OPERATE ALL GATES TO A 1FT OPENING. GATES NOT OPERATED DURING THE INFORMAL INSPECTION OR DURING A FLOOD SHOULD BE TEST-OPERATED DURING THE INTERMEDIATE INSPECTION (SEE CHAPTER 8 FOR A DESCRIPTION OF GATE TESTING).

PERIODIC ENGINEERING INSPECTION CHECKLIST
STRUCTURAL/MECHANICAL COMPONENTS
SPILLWAY GATES AND MACHINERY

__________________ PROJECT

INSPECTED BY: __________________________________ HW ELEV.: _______
DATE OF INSPECTION: ______________________________________

S–SATISFACTORY, U–UNSATISFACTORY (DESCRIBE UNDER COMMENTS)

GATE STRUCTURAL FEATURES
STRUCTURAL STEEL
_____ MEMBER DISTORTION, DAMAGE
_____ COATING CONDITION
_____ VEGETATION, DEBRIS
_____ EXCESSIVE CORROSION
GATE SEALS
_____ DAMAGE, WEAR
_____ EXCESSIVE LEAKS

HOIST MECHANICAL FEATURES
HOIST WORM REDUCER (QTY ____)
_____ ALIGNMENT AND WEAR
_____ OIL LEVEL
_____ OIL LEAKS
_____ DRAIN CONDENSATION
_____ PINION GEAR AND GEAR CASES
(QTY ____)
_____ OIL COATING ON GEARS
_____ DRAIN CONDENSATION

BRAKE (THRUSTER) (QTY ____)
_____ CORRECT ADJUSTMENT
_____ PROPER OPERATION
_____ SHOE CONDITION
_____ DRUM/GATE CONDITION
MACHINE BEARINGS
_____ LUBRICATION
LIFTING CHAINS/WIRE ROPE
_____ DAMAGE
_____ WEAR
_____ BROKEN LINKS/ WIRES
_____ MIC WIRES TO CONFIRM DIA.
GATE TRUNNIONS (QTY ____)
_____ LUBRICATE

GATE TEST OPERATION (1 FT. OPEN)
_____ UNUSUAL BINDING, VIBRATION
_____ TEST SLACK LIMIT SWITCH
(QTY ____)
_____ POSITION INDICATOR
_____ RECORD HOIST MOTOR VOLTAGE, AMPERAGE

GATE OPERABILITY TESTING
RECORD THE GATES THAT WERE TEST-OPERATED AND TO WHAT LEVEL (SEE NOTE 1).

1	2	3	4	5	6	7	8	9	10

INSPECTION COMMENTS (DESCRIBE UNSATISFACTORY CONDITIONS):
____
____
____
____

INSTRUCTIONS:

1. TEST-OPERATE ALL GATES TO A 1-FT OPENING. GATES NOT OPERATED DURING THE INFORMAL INSPECTION OR DURING A FLOOD SHOULD BE TEST-OPERATED DURING THE INTERMEDIATE INSPECTION (SEE CHAPTER 8 FOR A DESCRIPTION OF GATE TESTING).

CLOSE-UP ENGINEERING INSPECTION CHECKLIST
STRUCTURAL COMPONENTS
SPILLWAY GATES

_______________ PROJECT

INSPECTED BY: ____________________________ HW ELEV.: ______
DATE OF INSPECTION: ________________________________

S–SATISFACTORY, U–UNSATISFACTORY (DESCRIBE UNDER COMMENTS)

STRUCTURAL COMPONENTS
____ MEMBER DISTORTION
____ CRACKS IN WELDS
____ CLEAR DRAIN HOLES,
____ REMOVE TRASH
____ DIMENSION CHECKED
(SEE NOTE 1)
WELDED CONNECTIONS
____ CRACKS IN WELDS
____ POOR WELDS
RIVETED CONNECTIONS
____ LOOSE RIVETS
____ DETERIORATED RIVET
HEADS
SIDE SEALS
____ DAMAGE
____ WEAR
____ EXCESSIVE LEAKS

BOTTOM SEALS
____ DAMAGE
____ WEAR
____ EXCESSIVE LEAKS
SKINPLATE
____ CONDITION OF SKIN PLATE
____ THICKNESS
COATING, GENERAL CONDITION
____ COATING CONDITION
____ DEGREE OF CORROSION
GATE TRUNNION BEARINGS
(QTY ___)
____ LUBRICATE
LIFTING CHAIN/WIRE ROPE
____ BROKEN LINKS/WIRES
____ MIC WIRES TO CONFIRM
DIA.
____ DAMAGE

INSPECTION COMMENTS:
____
____
____
____
____
____

INSTRUCTIONS:
1 CHECK DIMENSIONS OF STRUCTURAL STEEL AND COMPARE TO DESIGN DRAWINGS.

CLOSE-UP INSPECTION CHECKLIST
STRUCTURAL MEMBER VERIFICATION
SPILLWAY GATES
_______________ PROJECT

GATE #: _______ DATE: ___________ INSPECTOR: _________________

STRUCTURAL MEMBERS:

MEMBER	ORIGINAL THICKNESS		ACTUAL THICKNESS		OVERALL DIMENSION		LOCATION
	WEB, T_W	FLANGE, B_F	WEB, T_W	FLANGE, B_F	WEB, T_W	FLANGE, B_F	
W14 X 84	0.451	0.778					MAIN STRUT, UPPER
W14 X 142	0.68	1.063					MAIN STRUT, MIDDLE AND LOWER
W14 X 34	0.287	0.453					VERTICAL STRUT STIFFENERS
W30 X 108	0.548	0.76					HORIZONTAL GIRDERS, UPPER
BUILT UP	9/16 IN.	1 IN.					HORIZONTAL GIRDERS, MIDDLE
BUILT UP	½ IN.	1 IN.					HORIZONTAL GIRDERS, LOWER
WT9 X 25	0.358	0.57					VERT. SKIN PLATE STIFFENERS
SKIN PLATE	3/8 IN.	N/A					

STRUCTURAL WELDS

LOCATION	ORIGINAL WELD SIZE	MEASURED WELD SIZE
VERTICAL STRUTS STIFFENERS, MAIN STRUT	3/16 IN.	
MAIN STRUT TO TRUNNION HUB PLATES, ONE SIDE	3/8 IN.	
MAIN STRUT AT GIRDER CONNECTION	3/8 IN.	
MIDDLE, LOWER HORIZ. GIRDER, WEB TO FLANGE	5/16 IN.	
TRUNNION, BOTH SIDES	3/4 IN.	

STRUCTURAL BOLTS

LOCATION	ORIGINAL BOLT DIA.	ORIGINAL BOLT HEAD	MEASURED BOLT HEAD
BETWEEN TRUNNION PEDESTAL AND ANCHORAGE	1-3/4 IN.	2-3/4 IN.	
MAIN STRUT TO GIRDER CONNECTION	3/4 IN.	1-1/8 IN.	
VERTICAL STRUT STIFFENERS TO MAIN STRUT	5/8 IN.	1-1/16 IN.	
TRUNNION HOLD DOWN BOLTS	2-1/2 IN.	3-7/8 IN.	

EMERGENCY GENERATOR INSPECTION

PLANT:	**CRAFT PERSONNEL:**
SIZE	**MANUFACTURER:**
PORTABLE ☐ **FIXED** ☐	**MANUFACTURE DATE:**
RUN TIME HOURS :	
ENGINE NAMEPLATE DATA:	

FLUID LEVELS / CONTAMINATION	**CONDITION**	**AFTER WARM-UP TIME GAUGES/LIGHTS OPERATIONS**
☐ **FUEL**	☐ **HOSES/BELTS**	☐ **OIL PRESSURE __ PSI**
☐ **OIL**	☐ **TIRES**	☐ **WATER TEMP ______ F**
☐ **BATTERY**	☐ **PAINT**	☐ **TACHOMETER (RPM)**
☐ **COOLANT**	☐ **LEAKS**	☐ **ALTERNATOR**
☐ **COOLANT GOOD TO ______ F (TEST)**	☐ **BATTERY CONNECTIONS**	☐ **OTHER PANEL LAMPS**

☐ **BLOCK HEATER OPERATION**
☐ **BATTERY CHARGER OPERATION**
☐ **BATTERY LOAD TEST**
☐ **BATTERY AGE ______ (REPLACE AT 4 YEARS) RECORD BATTERY INSTALL DATE:**
☐ **TIRE PRESSURE (CHECK TIRE FOR PRESSURE RECOMMENDATIONS)**
☐ **CORRECT HITCH AVAILABLE**
☐ **OIL/FUEL SPILL CONTAINMENT**
☐ **LOAD TEST OPERATION - RECORD LOAD USED AND HEADWATER ELEV.:**
COMMENTS :

INSPECTED BY: ____

DATE: _________________________

Appendix B: Gate and Operating Equipment Inspection and Testing Procedures

Inspection and Testing Process

1.0 Purpose - This Appendix documents an inspection and testing process for gates and gate operating systems for a dam.

2.0 Pre-Inspection Activities

- 2.1 Define the inspection objectives
- 2.2 Review previous inspection reports.
- 2.3 Review maintenance items generated since the last inspection for equipment to be inspected and tested.
- 2.4 Print copies of applicable checklists and other forms or references. Revise as necessary.
- 2.5 Review safety policy and establish procedures applicable to inspections
- 2.6 Review previous inspection reports and project drawings for each feature to be inspected.
- 2.7 Review O and M manuals, technical specification and drawings, etc.
- 2.8 Collect necessary checklists for the equipment to be inspected and tested.
- 2.9 Write inspection and testing procedures if not already written.
  - 2.9.1 Define personnel requirements
- 2.10 Schedule the inspection more than 30 days in advance.
- 2.11 Coordinate inspection and testing details with the site management.
  - 2.11.1 Coordinate time, date, and tasks to be performed.
  - 2.11.2 Coordinate support personnel requirements such as operation of equipment, electrical switching, opening gearboxes and electrical panels, etc.
- 2.12 Coordinate gate operations at the facility with the dispatch control center.
- 2.13 Identify required tools and instrumentation
- 2.14 Conduct pre-inspection meeting with appropriate personnel prior to scheduled inspection.

3.0 Inspection Activities

- 3.1 Perform the inspection in accordance with appropriate inspection procedures.

- 3.2 Obtain equipment nameplate data if not already available.
- 3.3 Document types of lubricant in use.
- 3.4 Review the monthly inspection checklists with maintenance personnel
- 3.5 Document coating condition
- 3.6 Include inspection activities for various gate types as per subsequent procedure lists

4.0 Operational Test

- 4.1 Review test operation procedures or develop these if not already written.
  - 4.1.1 A plan should be in place to address inability to close an opened gate. The options for minimizing consequences will vary depending on the gate and project specifics.
- 4.2 Review previous test operation reports and operational history.
- 4.3 Schedule test operations with site personnel and appropriate organizations.
- 4.4 Determine the required tests to be performed.
  - 4.4.1 Flood control spillway gates should be lifted at least one foot at a suitable reservoir elevation.
  - 4.4.2 Flood control spillway gates should be operated full travel every 5 years.
  - 4.4.3 Sluice gates should be operated full-travel at available head.
- 4.5 If applicable, inspect air vent to determine if any blockages exist.
- 4.6 Perform test operations using the primary power.
- 4.7 Perform test operations using the auxiliary backup power sources like diesel generators on at least one gate operation.
  - 4.7.1 Verify capability to operate manual and automated transfer switch. Switch should be used to transfer to secondary power source and operated at full load using this source.
  - 4.7.2 During testing, check for the symptoms of poor operation such as abnormal engine sounds or smells, unaccountable speed changes, and unusual temperature or pressure readings.
- 4.8 Operate gates using each method of control such as local, remote, and automatic control.
- 4.9 Monitor lifting effort by recording the hoist's motor line voltage and amperage.
- 4.10 Verify that the gate position indication device is working properly throughout the gate operation.

4.11 Verify limit switches are working properly and stop the gate at the correct location.
4.12 If applicable, test the brake to insure the gate is held in place.
4.13 During operations, check for unusual motor or gate noises, vibrations, gate binding, etc.
4.14 Check gate warning system if applicable.
4.15 Document the test operations, including gate number, gate run time, total travel, water level, number of start/stops and any unusual events or observations.

5.0 Post-Inspection Activities
5.1 Document inspection findings
5.2 Revise inspection checklists as necessary
5.3 Develop or update a lubrication lists to track lubricants utilized.
5.4 Conduct post-inspection meeting.

Radial Spillway Gate
Dam Safety Mechanical Inspection Procedure

1.0 Pre-Operation Inspection

Observe downstream and upstream sides of the gates. Inspect from as close as possible.

1.1 Seals and Seal Hardware

Look for damaged or missing seals. Check the condition of seal rubber. Note if material is stiff, cracked or chalky. Note location and amount of leakage past seals when gate is closed. Inspect hardware attaching seals to the gate. Note damaged or missing hardware. Observe and note amount of surface corrosion. If the reservoir is below the gate, the rubber seals should be moistened with water or a water/soap mixture prior to test operation.

1.2 Gate Structure

Look at the structural trusses or beams. Note bends, kinks, corrosive damage, missing welds, rivets or bolts. Inspect welded gates for cracked welds. Inspect riveted gates for rivets with corrosive head loss of fifty percent or greater. Note overall amount of surface corrosion. Note areas of paint damage or flaking that may indicate overstressed steel. Check for excessive amounts of debris that may clog drain holes and allow water to collect on horizontal members.

1.3 Skinplate (Upstream and Downstream)

Note deformations or cracks in the skinplate. Inspect the skinplate attachment to the support structure (trusses, beams, etc.). Note overall percentage of surface corrosion. Note depth of pitting due to corrosion.

1.4 Trunnions

Inspect trunnions for obvious exterior damage. If trunnion is bolted to a trunnion block, note if there are loose or missing attachment bolts. If trunnion pin has a keeper plate, inspect it for loose, missing or damaged hardware. If trunnions have thrust washers, inspect the outside edge for cracks and chips. If trunnions are lubricated, inspect the entire length of the lubrication lines for leakage and for a secure attachment. When trunnions are lubricated, note where excess grease is expelled. Compare this point with drawings to make sure lubricant is traveling across the length of the pin.

Inspect the trunnion anchorage assembly for damaged members, cracked welds, missing or damaged vertical and horizontal anchor bolts and corrosion damage. Note overall amount of surface corrosion on trunnion and trunnion block.

1.5 Embedded Sealing Plates and Guide Rollers/Bumpers

Check for missing or damaged guides. List the locations of missing or loose guide attachment bolts. Note the amount of clearance between guide rollers/bumpers and embedded seal plates. If gate has guide rollers, attempt to turn each roller by hand. Check rollers/bumpers for flat spots. Inspect embedded seal plate for scrape marks that indicate guide contacting with seal plate during gate operation. Note deformed or damaged areas on the embedded plate. Check for spalls in the grout or block out concrete around embedded seal plates. Look for water leakage through grouted areas.

1.6 Lifting Lugs

Look for damage and deformations to gate lifting lugs. Check lug attachments for loose or missing hardware or cracked welds. Note the overall surface corrosion and amount of metal loss due to corrosion. Check and record the amount of clearance between the chain attachment pin and the pin hole in lifting lug.

2.0 Test-Operation

2.1 Seals

Just as a gate closes, observe how water stops flowing from under the gate. Note if the flow stops on one side first, indicating that gate is being held up the chain/wire rope lifting elements on the leaking side more that on the sealing side. This observation can also be noted when a gate first opens.

2.2 Gate Structure

Observe gate operation for noise, squeaks, jumps, or intermittent movement. If seals have not been moistened, jumping or intermittent movement could be caused by dry seals. If seals have been moistened, they may be installed too tight. Note excessive flexure or vibration of structural members or of the entire gate.

2.3 Trunnions

Listen to trunnions using a stethoscope or a metal tool placed against the trunnion and pressed against the ear. Note popping or unusual noises coming from the trunnion. If gate is being operated full-travel and the trunnions are equipped with lubrication capabilities, the trunnions should be lubricated in the full open position and at 50% open.

2.4 Guide Rollers/Bumpers

Observe the guides during test-operation and note contact with the embedded side seal plate.

3.0 Post-Operation Inspection

3.1 Seals

Note amount and location of leakage after gates has been closed. Note if leakage has changed from before opening gate.

Wheel and Roller Mounted Gate
Dam Safety Mechanical Inspection Procedure

1.0 General Notes

1.1 If the gate is going to be operated with no flow or de-watered for inspection, stoplogs or an emergency gate must be placed in the secondary gate slot of the gate to be inspected or the water surface must be down below the gate opening.

1.2 If the gantry crane lifts the gate above the elevation of the operating deck, all aspects of the gates can be inspected from the operating deck.

2.0 Pre-Operation Inspection

2.1 Seals and Seal Hardware

Look for damaged or missing seals. Check the condition of seal rubber. Note if the material is stiff, cracked or chalky. Note location and amount of leakage past gate seals when the gate is closed. Inspect hardware attaching the seals to the gate. Note damaged or missing hardware. Observe and note amount of surface corrosion on seal backing bar and bolting. If the reservoir is below the gate, the rubber seals should be moistened with water or a water/soap mixture prior to test-operation.

2.2 Gate Structure

Look at the structural girders, end plates, and stiffeners. Note bends, kinks, corrosive damage, missing welds, rivets or bolts. Inspect welded gates for cracked welds. Inspect riveted gates for rivets with corrosive head loss of fifty percent or greater. Note overall amount of surface corrosion. Note areas of paint damage or flaking that may indicate overstressed steel. Check for excessive amounts of debris that may clog drain holes and allow water to collect on horizontal members.

2.3 Skinplate (Upstream and Downstream)

Note deformations or cracks in the skinplate. Inspect the skinplate attachment to the support structure (trusses, beams, etc.). Note overall percentage of surface corrosion. Note depth of pitting due to corrosion.

2.4 Embedded Seals and Guides

Check for missing or damaged guides. List the locations of missing or loose guide attachment bolts. Note deformed or damaged areas in embedded seal or guide plates. Check for spalls in the grout and blockout concrete around the embedded seal plates. Look for water leakage through the grouted areas.

2.5 Gate Wheels

Gate wheels and rollers should turn freely by hand. Note flat areas on the contact points of the wheels and rollers that may indicate past or present sliding of wheels and rollers. Note leakage of lubricant from wheel or roller hubs or axles. Check axle connection points for loose or missing connection bolts/rivets and missing keeper plates/bars.

2.6 Lifting Hooks

Look for damage and deformations to hooks. Check hook attachments for loose or missing hardware or cracked welds. Note the overall surface corrosion and amount of metal loss due to corrosion.

2.7 Lifting Beam

The lifting beam should be observed for fitness of duty due to its critical nature. Check lifting points for cracks and deformations. Make sure the lifting point articulates as designed for proper operation. Look at internal linkages and gearing for damage and lubrication. Check wire rope sheave connection points for damage or missing retention devices.

3.0 Test Operations

3.1 Seals

Just as a gate closes, observe how water stops flowing from under the gate. Note if the flow stops on one side first, indicating that gate is being held up by the chain/wire rope lifting elements on the leaking side more than on the sealing side. This observation can be noted when a gate first opens.

3.2 Gate Structure

Observe gate operation for noise, squeaks, jumps, or intermittent movement. If a noise is heard, investigate further for metal - metal contact. If seals have not been moistened, jumping or intermittent movement could be caused by dry seals. If seals have been moistened, they may be installed too tight. Note excessive flexure or vibration of structural members or of the entire gate.

3.3 Lifting Beam and Lifting Hooks

Just prior the lifting each gate, observe the top of the gate for debris that may prevent the lifting beam hooks from engaging with lifting lugs on the gate. Inadequate engagement may result in failure to lift and/or a bound or dropped gate.

4.0 Post Operation Inspection

4.1 Seals

Note amount and location of leakage after the gates have been closed. If applicable, note if different from the beginning of the inspection.

Hydraulically-Operated Slide Gate Dam Safety Mechanical Inspection Procedure

1.0 Pre-Operation Inspection

1.1 Visual

1.1.1 Slide Gate

Check overall condition of gate for corrosion. Check for leaks past seal. If dewatered, check for excessive play of gate in gate slot. Inspect the gate seal bars and embedded seal seats for pits and nicks. Ensure that seal seat bolts are intact and tight. If possible check the connection of the gate stem to the gate leaf.

1.1.2 Bonnet

Look at slide gate bonnet exterior for paint condition, corrosion, and damage. Look at bonnet flanges and cylinder head connection for loose or damaged bolts, corrosion, and lubrication leaks. Check packing glands for leakage. Check concrete base for spalls or cracks.

1.1.3 Hydraulic System

Look at hydraulic fluid lines for damage and leaks. Pay particular attention to coupling and valve connection points. Check directional valves, synchronizing valves, shut-off valves, and regulating valves for operability.

1.1.4 Stem and Dogging Device

Inspect gate stem contours and check for straightness of stem. Ensure safety stud is not broken and that the safety stud cap is tight. Ensure safety stud cap is secured to counterweight system. Look at dogging device and safety stud cap exterior for paint condition. Check for proper operation of the dogging device and counterweight system.

1.1.5 Refill Valves

Look at refill valves exterior for paint condition. Check for leakage past packing gland.

1.1.6 Vent Check Valves

Look at check valves exterior for paint condition. Inspect the concrete around the check valve conduit for spalls or cracks. Ensure the check valve stand is properly anchored to the ground.

1.1.7 Oil Tank

Look at the oil tank exterior for paint condition. Check for leaks where fluid lines enter and leave tank. Inspect the concrete base of the tank for spalls or cracks.

1.1.8 Relief Valves

Look for leaks around system relief valves.

1.2 Lubrication

Check oil levels in tank. Check for condensation in the tank. Check for lubrication on the dogging devices, check valves, motors, and pump.

2.0 Test-Operations

2.1 Check the primary relief valves before operating slide gates by allowing them to by-pass hydraulic fluid.

2.2 Follow operating instructions for test operation.

2.3 Visual and audible inspection

2.3.1 If dewatered, inspect gates through their full-operating range. If possible, ensure that stem connection to gate leaf does not rotate during initial operation.
2.3.2 Look for new lubrication leaks in fluid lines during and after operation.
2.3.3 Look for new lubrication or water leaks around bonnet stem glands during and after operation.
2.3.4 Listen for unusual sounds during gate operation.
2.3.5 Ensure gate dogging device operates properly.
2.3.6 Listen to motor bearings for unusual sounds or movement. Check the motor housing for excessive heat.
2.4 Perform vibration analysis
2.5 Collect motor current data
3.0 Post Operation Inspection
3.1 Oil Samples
Draw one 750mL sample from the slide gate oil tank, checking for water, old oil that is turn acidic, incorrect oil, and metal in the oil indicating excessive wear in gears, bearings, or bushing. This type of sampling is a very good predicative maintenance indicator.

Regulating Sleeve Valve Dam Safety Mechanical Inspection Procedure

1.0 Pre-Operation Inspection
1.1 Visual
Inspect the valve body anchor bolts for loose or missing nuts, loss of form, and excessive corrosion. Inspect sleeve face and packing gland bolts for loose or missing nuts, loss of form, and excessive corrosion. Look at welded connections on valve body for cracks or deformations. Inspect gearbox connections for loose hardware and oil leakage. Inspect threads on drive screw for wear. Note locations of water leakage from the upstream seat and downstream seal. Note the overall percentage of surface corrosion. Note condition of coatings on valve sleeve, gear boxes, and shafts. Inspect shaft coupling(s) and note condition of coating and hardware. Inspect the coupling bolts for tightness. Inspect intermediate shaft bearing(s) noting coating, anchor hardware, brace, and brace anchor.
1.2 Lubrication
Note the lubricant levels in the bevel and worm gearboxes. Check for and drain condensation/water ingression from gearboxes.

Inspect lubricant coverage on drive screw, drive nut, and barrel. If drive nut has a spring loaded lube cup or lubrication system, check the level in the lube reservoir. If applicable, check shaft couplings for lubrication condition. Check intermediate shaft bearing(s) for lubrication. Check button head fittings for lubrication.

2.0 Test-Operations

Test-operation of a sleeve valve will include full-travel operation with no flow. Refer to the project specific inspection procedure for required flow testing.

2.1 No Flow

2.1.1 Valve Exterior

2.1.2 Watch rotating shafts for unusual movement. Listen for unusual noises from the gearboxes. Observe sleeve travel for racking, rotation, or movement that is not parallel to the valve body.

2.1.3 Valve Interior

2.1.4 Look at seats where any leakage may have been noted prior to valve isolation. Note gouges left by erosion on the sleeve or seat surfaces. Inspect vane weld connections to cone and valve body. Look for cracks or damage to welds. Note deterioration due to corrosion and overall condition of vanes. Check interface between valve and sluice conduit for an uneven transition, cavitation or other damage. Note overall percentage of surface corrosion and damage/pitting caused by corrosion.

2.2 Flow

Listen for loud cavitation sounds (popping) and vibration. Watch valve body, cone and vanes for movement. Watch shafts for variations in movement from no flow operation. Observe flow pattern for unusual conditions.

3.0 Post Operation Inspection

3.1 Lubrication Inspection

If the gearboxes are oil filled, draw an oil sample. Note location of water leakage from upstream seat and downstream seal and compare to pre-operation locations.

4.0 Safety

4.1 The valve interior should only be inspected after machinery that operates the isolating valve and regulating sleeve valve machinery have been locked and tagged out.

4.2 If the valve diameter is greater than 36 in., an inertia locking safety real and a body harness should be used to gain access to sleeve valve. Use of water repellant clothing and rubber boots are recommended.

Fixed Gate Hoist for Various Gate Types Dam Safety Mechanical Inspection Procedure

1.0 Pre-Operation Inspection
- 1.1 Visual
  Look at hoist exterior for paint condition, corrosion, and damage. Look at hoist bases for loose or damaged grout, gearboxes, equipment, and corrosion.
- 1.2 Lubrication
  Check oil levels in gearboxes. Check for condensation in the gearboxes. Check pillow block bearings and shaft couplings for lubricant condition. Look at open gear reducers and check for tooth wear, lubrication coverage and condition of lubricant.
- 1.3 Brake Inspection - See Brake Inspection Procedure.

2.0 Test Operation
- 2.1 Visual and audible inspection
  - 2.1.1 Listen to motor bearings for unusual sounds. Feel motor housing for excessive heat.
  - 2.1.2 Listen to worm gearboxes, parallel shaft reducers, open gear reducers, and pillow block bearings for unusual sounds. Feel the housing of the first stage of gear reduction for excessive heat.
  - 2.1.3 Watch chain engagement on sprocket/pocket wheel. Inspect chain/wire rope for damage. Inspect the chain/wire rope attachment to the gate for damage or excessive corrosion.
  - 2.1.4 Watch shafts and couplings for misalignment and imbalance.
  - 2.1.5 Observe brake shoes engage and release. Take appropriate brake measurements as required in Brake Inspection Procedure.
- 2.2 Collect motor current data

3.0 Post Operation Inspection
- 3.1 Oil Samples
  Draw one 250mL sample from each worm gearbox and parallel shaft reducer (when part of the machinery), checking for water, old oil that is turn acidic, incorrect oil, and metal in the oil indicating

excessive wear in gears, bearings, or bushing. This type of sampling is a very good predicative maintenance indicator.

Brake Inspection
Dam Safety Mechanical Inspection Procedure

1.0 Pre-Operation Inspection

- 1.1 Thrustor Brake
  - 1.1.1 Remove brake cover. Observe if there is a dusting of a dark powder on all surfaces. This could be a clue that brakes are dragging, that calipers are not opening or that brakes are heavily used. Also note percent of surface corrosion.
  - 1.1.2 Check if brakes appear to be loaded or if they will back-peddle if disengaged. If loaded, carefully lift thrustor rods. Note if they rise smoothly and return quickly to the same position. Also, note if pads are equally separated from drum.
  - 1.1.3 Push down on rods and note if they move downward.
  - 1.1.4 Check pad condition and note if they are thin, cracked or have missing pieces.
  - 1.1.5 Check surface condition of the drum for grooves, pits, and other irregularities.
  - 1.1.6 Note other obvious damage to operating linkages, wiring, drum, and thrustor.
- 1.2 Motor Brake
  - 1.2.1 Remove brake cover. Observe if there is a dusting of a dark powder on all surfaces. Also, note the percent of surface corrosion.
  - 1.2.2 Manually disengage brake and observe if disks loosen or separate. Note if brake operates smoothly and freely.
- 1.3 Lubrication (Thrustor only)
  Check for oil seepage from rods or other penetrations in reservoir. Check oil condition and level in gearbox by unscrewing level plug.
- 1.4 Measurements
  - 1.4.1 Thrustor
    Measure the rod height from top of the thrustor reservoir to the bottom of the rod to lever connection. Measure the brake pad thickness. Measure return spring length.
  - 1.4.2 Motor Brake
    Measure the brake pad thickness.

2.0 Test Operations

2.1 Visual and Audible Inspection

2.1.1 Thrustor Brake

2.1.2 Listen for hisses, squeaks, scraping, and other unusual operating sounds. Check if pads have cleared the drum. Note speed at which thrustor rods rise and lower. Observe drum rotation and note movement other than axial rotation.

2.1.3 Motor Brake

2.1.4 Listen for hisses, squeaks, scraping and other unusual operating sounds. Observe solenoid operation. Note if brake disks are binding.

2.2 Measurements (Thrustor only)

While machinery is operating, perform following measurements.

2.2.1 Measure rod height from the top of thrustor reservoir to bottom of the rod to lever connection.

2.2.2 Measure space between brake pad and brake drum.

2.2.3 Measure return spring length.

2.3 Adjustments (Thrustor only)

If rod height at rest and spring compression measurements do not fall within parameters suggested by the Thrustor Brake Inspection Datasheet (See page B-14), the brake should be adjusted during the inspection. If brake pad is dragging on the drum or the stem is rising too quickly or slowly, this should also be corrected during the inspection by performing necessary adjustments. The brake should be retested after adjustment to assure its performance. The adjustment procedure is also found on the attached Thrustor Brake Data Sheet (See page B-14).

3.0 Post Operation Inspection

3.1 Lubrication (Thrustor only)

Ask plant personnel what kind of oil is being used to top off thrustor reservoir.

3.2 Replace brake cover.

4.0 Safety

4.1 Particular attention should be given to safety while inspecting brake. Great care should be taken with loose clothing or body part, which may become tangled in drum or operating mechanisms during operation.

4.2 While taking measurements, do not insert fingers or body part near the brake. Insert only the tip of a measuring device into the area where the measurement is to be taken.

4.3 If brake is not operating, do not assume that it will remain inoperable unless it is properly tagged out of service and thrustor motor is unwired.

Thrustor Brake Inspection Data Sheet

1.0 Check fluid level. Add fluid if necessary. Shell Spindle Oil 10 is the recommended replacement fluid. Different type oils should not be mixed.
2.0 Record the information with the brake set and with it actuated.
3.0 Inspect brake drum for pitting or scoring.

<u>Acceptable Dimensions (See Sketch)</u>

A - Greater than ½-in.
B, C - Greater than ½ original pad thickness

N, O - Should be 1/32 to 1/16 and equal

M and L are for reference only

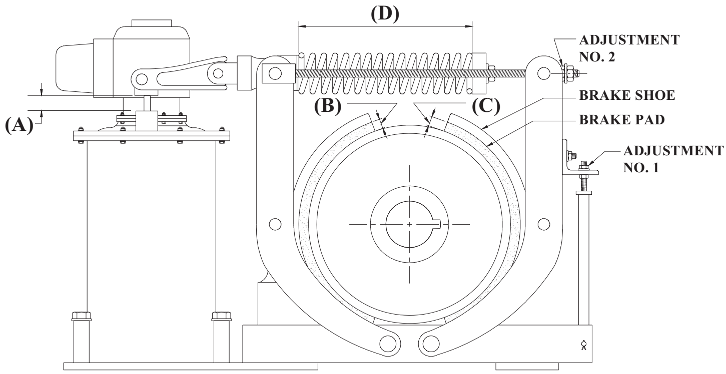
<u>Adjustments</u>

If A is less than ½-in., adjust connecting rod nuts (adjustment no. 2) until gap is greater than ½-in. After adjustment, the operating clearance (N and O) must be rechecked and readjusted if necessary as described below.

If B or C is less than ½ original pad thickness, new pads should be installed. Note: old pads are most likely asbestos.

If the operating clearances N and O are not equal, adjust backstop (adjustment no. 1) until gap is equal.

Record Nameplate Data



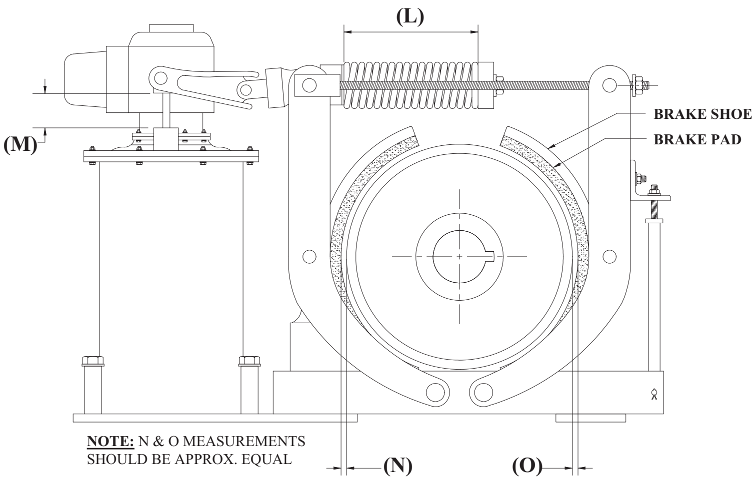
THRUSTOR IN SET POSITION

_________ **(A)** GAP WHEN THRUSTOR IS SET

_________ **(B)** PAD THICKNESS (INBOARD)

_________ **(C)** PAD THICKNESS (OUTBOARD)

_________ **(D)** SPRING LENGTH



THRUSTOR IS ACTUATED

_________ **(L)** SPRING LENGTH

_________ **(M)** GAP WHEN THRUSTOR IS ACTUATED

_________ **(N)** OPERATING CLEARANCE (LEFT SIDE)

_________ **(O)** OPERATING CLEARANCE (RIGHT SIDE)

Dam Safety Inspection Procedure
Engine Driven Generator

1.0 Pre-Operation Inspection

1.1 Visual

1.1.1 Generator housing and fuel/oil containment

Look for damage to generator housing, if one exists. Look for leaks in roof. Check for adequate ventilation of engine exhaust and cooling air. Look at fuel/oil containment if it is built into the housing. Make sure there are no major foundation cracks that could allow spillage to escape. Inspect generator housing for paint condition and leakage.

1.1.2 Generator support

If generator has tires record the tire pressure. If generator has jack stands, make sure they are secure. Check if there are rubber dampers on the stands. If the generator is not on a trailer, check if base of the unit is secure.

1.1.3 Belts and hoses

Inspect belts for cracking and age related damage. If belts are touching the bottom of the V-notch on pulley, they should be replaced. Check for cracks, bulges and other signs of deterioration in engine coolant hoses.

1.1.4 Battery age, charger, and connections

Note the battery's age. If it is four years old or greater, recommend replacement. Look at charger and make sure it is operational. Inspect the battery connections for looseness and corrosion. Clean off corrosion and tighten terminals if necessary.

1.1.5 Engine block heater

Check engine block heater by touching the engine block to feel if it is warmer than ambient temperature.

1.1.6 Air filter

Open air filter canister and check cleanliness of filter.

1.2 Lubrication and Fluids

1.2.1 Check level and condition of engine oil. Record when the last oil change was made if date is available. Oil should be change every 250 hours or every year, whichever comes first. Ask plant personnel what type of engine oil is used.

1.2.2 Check coolant for level and condition. Test coolant with a hydrometer and record temperature at which coolant will freeze.

1.2.3 Check fuel level and condition. If the fuel filter can be observed, see if there are contaminants in it. Check to see when the fuel filter was last changed or cleaned. Check fuel lines for leaks. If fuel system has heaters, their integrity and operation should be checked.

1.2.4 Look into each battery cell for water level.

1.3 Data Collection

1.3.1 If name plate data is not recorded, record engine and generator nameplate data. If data is recorded, note changes made and change data on checklist.

1.3.2 Record run time meter.

2.0 Test-Operations

2.1 Audible and Visual

2.1.1 Start up

The engine should start quickly on the first attempt. The cause of failure to start should be identified and remedied.

2.1.2 Engine Idle

Listen for vibration outside of normal operation. Look for unusual movement. Engine should idle at a constant speed (~1800 rpm).

2.1.3 Load Test

Engine will not likely sound loaded when normal operational loads are used. If a load bank is used during test-operations, a load of at least 10% of rated capacity must be used for the engine to sound loaded. When the load is applied, the engine will release a small amount of smoke, and engine rpm will slow and quickly return to original speed.

2.1.4 Shut down

The shut down should be quick and without “dieseling.”

2.2 Data Collection

During the load test, record engine coolant temperature, rpm, oil pressure, and alternator output. Record the panel warning lamps that are illuminated.

3.0 Post-Operation Inspection

3.1 Oil Sampling - Draw a 500mL sample, checking for water, old oil that is turn acidic, incorrect oil, and metal in the oil indicating excessive wear in gears, bearings, or bushing. This type of sampling is a very good predicative maintenance indicator.

3.2 Data Collection

Record the engine run time meter.

4.0 Exceptions and Additions

4.1 For propane fueled emergency generators, follow the above procedures and the checklist with the addition of observing propane fuel level, condition of propane tank, and condition of propane supply line to generator engine.

Appendix C: Crane Inspection Activities

Implementing an Effective Crane Inspection Program

1. Define objective of the inspection program.
2. Types of programs with differing activities and focal points.
3. Documentation for reporting data and tracking results.
4. Define categories of procedures, such as;
   a. reporting routine matters
   b. establishing priorities
   c. instituting action levels if the potential for a catastrophic event is discovered
5. Defines pre-inspection and preparation activities such as;
   a. defining personnel requirements and qualifications
   b. defining and identifying the roll and responsibilities of interfacing personnel and departments
   c. identifying required tools and instrumentation
   d. review of applicable codes and standards
   e. establishing and understanding criteria and parameters
   f. describing safety violations and when they become urgent
6. Establishing a reporting method and documentation
   a. defining deficiency levels
   b. defining reporting methods and procedure
   c. defining levels of authority for inspectors

Phases

Effective inspection programs have four distinct phases. They are:
1. pre-gathering data activity,
2. gathering and recording data,
3. reviewing and analyzing data and
4. finally, reacting to the data

How It Fits Together

1. Policy gives direction to the entire program and provides the basic “marching order” for all involved personnel. This is especially critical for avoiding conflict between departments such as production and safety departments (or those charged with safety).

2. Defining the objective is necessary for an effective inspection program. It provides basic direction for inspector's activities and focus as well as personnel dealing with the collected data.
3. Establishing basic criteria assures efforts will be aimed toward meeting the objectives.
4. Knowing and understanding applicable codes provides guidelines for meeting safety requirements, compliance with law and insurance criteria.
5. Documentation provides the necessary proof inspections have been performed as well as providing a vehicle for managing equipment.
6. Defining the roles of effected individuals and departments creates the basis for teamwork and cooperation. Understanding the importance of those roles by all parties is paramount for success.
7. Establishing methods assures the inspections will be conducted in a consistent, high quality manner.
8. Defining a reporting procedure assures complete proper information is delivered to the appropriate destination on a timely basis.
9. Analysis of the data maximizes the benefits of inspections by utilizing the data to manage the equipment in a more efficient manner.

Define Inspection Policy

Creating a mission statement expresses the intention of management. Delineating policy communicates management's commitment and provides guidelines for setting priorities. Correction of potentially catastrophic deficiencies in cranes are deferred with significantly risk to safety and/or substantial cost increase as well as extended loss of equipment usage because mid-management won't stop to make the correction. REASON – they perceive top management considers the corrections to be less important than production.

An example of an effective mission statement: "This organization is dedicated to providing our staff with safe, functional, productive tools and equipment. To this end, we conscientiously monitor and maintain equipment while giving safety the highest priority.

Safety Policy and Procedure Applicable to Inspections

1. Relative to operator
   a. Institute operator inspection procedure at the beginning of each shift as well as a reporting method
   b. Review inspection policy and procedures with operating personnel and supervisors

   c. Make certain operators understand they are to follow instructions designated inspectors ONLY, while crane operation is being observed for inspection purposes.
   d. Create “no entry perimeters” under the crane with safety tape and cones.
   e. Establish “lock-out/tag-out” procedures must be honored by all personnel.
   f. Let personnel know that under no circumstances is the operator permitted to operate a crane being inspected until permission is given by the inspector.
2. Relative to inspectors
   a. Review policies, procedures and expectation with inspectors.
   b. Inspectors must consider their personal safety to be the highest priority when inspecting a crane. This includes using proper use of personal protection equipment, fall protection and safeguarding against electrical shocks.
   c. Cranes must be properly locked-out, tagged-out prior to boarding with exception of operational inspection phase (if applicable). During that phase, the inspector must closely communicate with the operator.
   d. Establish “No entry” perimeter during inspection.
   e. Require inspectors to account for inspection tools prior to turning the crane over to operations and restarting equipment.
   f. Identify and address hazardous environment precautions as applicable.
   g. Stipulate safety deficiencies are to be reported immediately.
   h. Conditions discovered with potential for catastrophic consequences are to be acted upon immediately and reported to upper management.

Types of Inspections

1. Preventative Maintenance
   a. Primarily checks lubrication levels and greases appropriate components, while checking oil levels and topping off as needed, visually inspecting brake wear, sheave wear, wheel wear and wire ropes.
   b. Operates visual and audible functional testing of overall operation with additional testing if suspect sounds or operation is observed.
2. Predictable Maintenance
   a. This is much more comprehensive than preventative maintenance. It looks at lubrication levels and includes greasing appropriate components. It also takes samples of grease and checks for metal specs and break down.

b. Checks oil levels and tops-off as needed but also takes a sample of the oil and has it analyzed.
c. Inspects brake wear and measures disc, shoe and/or pad thickness. Measures sheave wear, wheel wear and wire ropes with calipers and documents progression of deterioration.
d. Compares inspection results with previous data for forecasting the timing for acquisition of parts and determines a schedule for replacement.
e. Visual and audible inspection of each part and component (where practical)

3. Satisfying OSHA
   a. Initial Inspection
      i. "Initial inspection" applies to new, repaired, re-assigned equipment ASME B30.2-2001 requires *Initial Inspection* for new, reinstalled, altered, repaired and modified cranes. It must be completed prior to initial use to verify compliance with applicable provisions in the volume. Inspection of altered, repaired and modified cranes may be limited to the provisions affected by the alteration, repair or modification as determined by a qualified person. Also requires operational and load testing.
      ii. Initial inspections also serve as a base line for establishing predictable maintenance.
4. Frequent OSHA Inspection
   a. Based on ASME B30.2-2001Section 2-2.1.1

"Frequent Inspection" Schedule Based on ASME B30.2-2001Section 2-2.1.1		
Usage		Stand-By
CMAA Service Class	ASME B30.2 Service Class	
		Frequency of Inspection
A	Normal	NA
B		Monthly

5. Periodic OSHA Inspection
   a. Based on ASME B30.2-2001Section

"Periodic Inspection" Schedule Based on ASME B30.2-2001Section 2-2.1.1		
Usage		Number Of Shifts Operated Per Day
CMAA Service Class	ASME B30.2 Service Class	Stand-By
		Frequency of Inspection
A	Normal	Annually
B		

Define Objectives

1. Multi-purpose inspections, organizing and analyzing data.
   a. Inspections are a means for cost reduction. Gathering the proper data and analyzing effectively reduces cost by forecasting manpower requirements, scheduling repairs before breakdowns occur, reduce need for unnecessary parts inventory by forecasting replacement timing.

External Codes and Requirements

1. It is very important to identify and obtain applicable codes and documents. First, define documentation requirements. They include:
   a. Internal Safety Programs and Requirements – As applicable
   b. Industry standards – As applicable
   c. State and Local codes – As applicable
   d. NAV FAC Requirements – As applicable
   e. ASME B30.2 and associated standards applicable to Cranes – Required
   f. ASME B30.10 standards for hooks – Required
   g. ANSI A1264.1 guard railings and toe guards – Required
   h. ANSI SAE Z26.1 cab window glazing – Required for outdoor cab operated cranes
   i. CMAA Specification #70 or #74 – Required
   j. CMAA CMSC Specification for Inspections – Recommended
   k. National Association for Fire Protection Standards, NEC Article 610 – Required
   l. National Association for Fire Protection Standards Relative to hazardous environments – As applicable for crane environment

   m. Manuals and instruction information by Crane manufacturer's Operation and Maintenance manual – Recommended
   n. Parts and Component manuals and procedures from, gear reducer, coupling, electrical controls, motor manufacturers – Recommended

Define Personnel Requirements

1. Ergo: Is sole inspector required?
2. Is helper required?
3. Are separate mechanical and electrical Inspectors required?

Define Inspection Staff Qualifications

1. Determine requirements for training.
2. Decide level of experience required.
3. Is a high level of competency required? Determine how to establish level of competency required and establish a means to measure it.

Identify Roles and Responsibilities

1. Group Leader Responsibilities
   a. Group Leader will conduct a pre-task briefing with personnel involved to cover hazards and safety precautions. New personal are to report to the Group Leader for a pre-task briefing and status updates.
   b. Verify the operator's certification.
   c. Ensure personnel directly involved know the applicable requirements.
   d. If the average usage of this crane changes, notify Facilities Engineering to evaluate the need to increase or decrease frequencies of certain tasks in this procedure.
   e. Sign and date the major grouping steps for "Mechanical," "Electrical," and "Oiler" signifying completion of group.
2. Craftsman Responsibilities
   a. Record calibration for applicable equipment.
   b. Post warnings signs and alert personnel that crane operations/ inspection/maintenance are about to begin. Clear non-essential personnel from the immediate area.
   c. Initial and date each step signifying completion of step.
3. Facilities Engineering Responsibilities
   a. Evaluate the need to increase or decrease frequencies of certain tasks when notified usage of the crane has changed.
   b. This PM Procedure is based on an average usage of that of a Class C (Moderate Service) Crane. In this type of service the crane will handle

loads which average 50% of the rated capacity with 5 to 10 lifts per hour, averaging 15 ft, not over 50% of the lifts at rated capacity.

4. Collective Responsibilities
   a. Note discrepancies and problem concerns. Attach separate list.
   b. Read and heed Warning, Cautions, and Notes.
   c. All adjustments/corrections are to be noted and distributed to affected personnel. Attach separate list if additional space is required.

Become Familiar with the Equipment

1. Understand the function of the equipment and its role in the overall facility
2. Review the Operating and Maintenance manual
3. Review electrical and control diagrams
4. Become familiar with features incorporated with the equipment

Identify Required Tools and Instrumentation

1. Safety harnesses and equipment
2. Wrenches
3. Screw drivers
4. Calipers
5. Feeler gages
6. Specialized Electrical Instruments (Laptop, Software, Connection cables)
7. Insulation resistance testing (Meg-Ohm) Amp meters
8. Continuity testers
9. Verify accuracy of calibration of each tool (If applicable)

Define Purpose of Data and Post Inspection Processes

1. Establish an equipment analysis for overhaul or replacement
2. Data can be gathered to track expenses and isolate repetitive problems, analyze ROI, and determine plan of action for cost reduction.
3. Data can be used for planning production outages and activities
4. Data provides a means for major forecasting repairs and modifications that may be scheduled for off shift, weekends or production down time.
5. Data can be used for forecasting work load and staffing requirements
6. Once scope of work is established considering internal resources and need for outside contractors can be determined.
7. Predicting maintenance repairs and parts acquisition
8. Investment in parts inventories can be reduced by closely monitoring cranes and ordering parts based on forecast rather than "just in case" basis.

PARTIAL SAMPLE OF AN INSPECTION FORM							
CRANE CONDITION LOG							
Date		CRANE IDENTIFICATION					
Instructions:		Note the hour and cycle count display as well as hours and cycles since last entry					
Evaluate each component on a scale of 1 to 5. 1 = new or excellent condition, 2 = Good Condition, 3 = Fair Condition and monitoring, 4 = poor condition and requires close monitoring and 5 = replace immediately.							
Date	Component	Recorded Running Hours =	Hours since last inspection	Cycle Count =	Cycles since last inspection	Condition	Remarks
	Hook						
	Safety latch						
	Safety latch spring						
	Hook nut						
	Bottom block						
	Sheaves						
	Sheave pins						
	Sheave pin keeper						
	Wire rope						
	Upper sheaves						
	Upper sheave pins						
	Equalizer sheave						

Identify Deficiency Levels

1. Aesthetic but not functional (Looks ugly but will not affect functionality of equipment. Ergo: Cracked window, chipped paint)
2. Minor functional (Will not seriously affect function, easily repaired. Ergo: High bay work light lamp not functioning.)
3. Major functional (Will put equipment out of commission). Ergo: A short circuit in the electrical system.
4. Operational Catastrophic (Will put equipment out of commission and cause extensive damage, extended down time. Ergo: Gear reducer without oil.)
5. Safety Catastrophic (Threatens safety of personnel and surrounding equipment with potential load drop. Ergo: Faulty holding brake, excessive broken strands in wire rope.)
6. Safety non-catastrophic but requires immediate attention. Ergo: A broken warning sirens or missing capacity signs.
7. Safety non-catastrophic but requires does not require immediate attention. Ergo: A missing coupling guard on bridge drive will not be safety issue until the next time someone boards the crane.

Define Reporting Procedure for Each Level of Deficiency

1. Who is notified and what immediate steps are to be taken when a catastrophic condition is identified. Define department and level of management to be notified after inspector tags the crane. Since there will be production ramifications from losing the crane. Production needs to be notified. Engineering, purchasing and maintenance will be involved in the correction therefore they need to be notified. If there is a safety department, they will oversee the correction and re-instatement of the crane into use.
2. Define the purpose of each contact.
3. Ergo: A catastrophic safety deficiency is identified. Does inspector contact plant manager, engineering, and maintenance? What action is required on the part of the person contacted?
4. Define Authority Level the Inspectors
5. Do they have the authority to immediate order cessation of equipment use if a catastrophic safety deficiency is discovered? If the inspector does not feel they will be able to tag the crane without suffering ramifications or reprisal, trouble is brewing,

Define Inspector's Authority

1. Define Inspectors Authority and Communicate It To All Parties.
2. Do they have the authority to order immediate cessation of equipment use if a catastrophic safety deficiency is discovered?

Summary

1. In order to establish and effective inspection program, one must:
    a. Communicate inspection policy
    b. Understand types of inspections
    c. Set safety policy and procedures
    d. Define objectives
    e. Establish reporting method and documentation
    f. Identify personnel requirements and qualifications
    g. Delineate roles and responsibilities of staff and department
    h. Identify required tools and instrumentation
    i. Classify deficiency levels
    j. Institute reporting methods and procedure
    k. Provide inspectors with necessary authority

Appendix D: Curvilinear Pressures

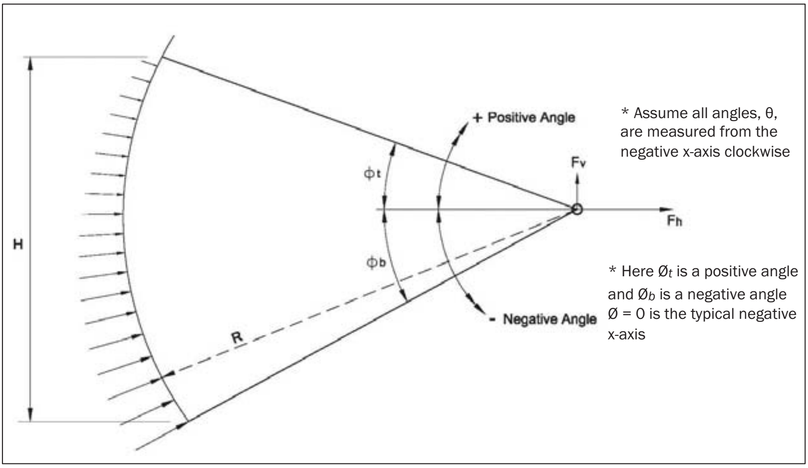
Derivation of F_H, F_V, Sum of Pressures Due to Curvilinear Hydrostatic Loads

1.0 Equations in Chapter 9

$$F_H = (62.4\,WH^2/2) = (62.4\,WR^2/2)(\sin\emptyset_t - \sin\emptyset_b)^2$$

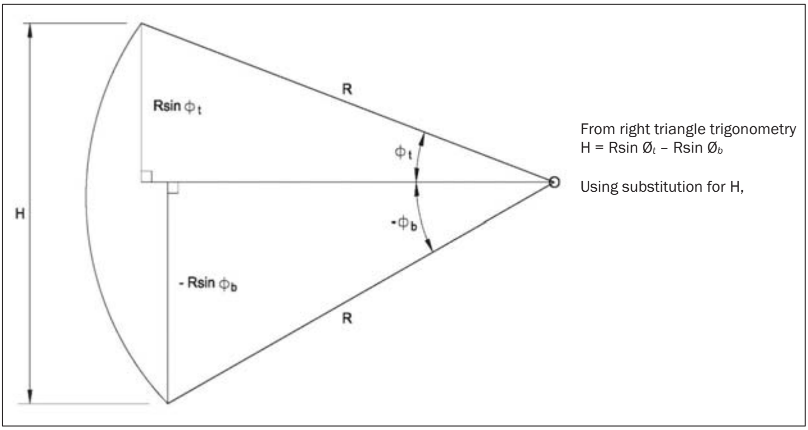
$$F_V = (62.4\,WR^2/2)\,[\sin\emptyset_b \cdot \cos\emptyset_b - 2 \cdot \sin\emptyset_t \cos\emptyset_b + \cos\emptyset_t \sin\emptyset_t + \emptyset_t - \emptyset_b]$$

W = Overall width of gate in feet
H = Vertical height of the gate in feet
R = Radius of the gate
$\emptyset_b$, $\emptyset_t$ = See figure



$$Magnitude\ of\ vector\ at\ \theta = \emptyset_t \Longrightarrow Vector\ length = 0$$

$$Magnitude\ of\ vector\ at\ \theta = \emptyset_b \Longrightarrow Vector\ length = 62.4\,W\,H$$



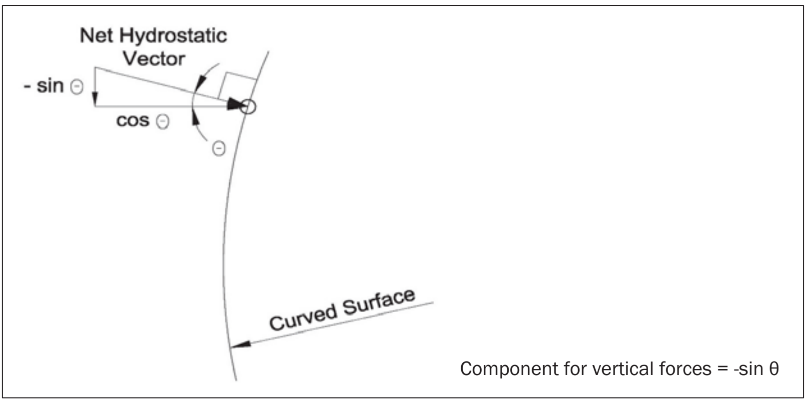
2.0 Horizontal Force Derivation

$$F_H = (62.4\, WH^2/2) = 62.4\, ((\sin\emptyset_t - \sin\emptyset_b))^2/2$$
$$= (62.4\, WR^2/2)(\sin\emptyset_t - \sin\emptyset_b)^2$$

3.0 Vertical Force Derivation

Magnitude of an arbitrary hydrostatic vector @ Ø
$\Rightarrow$ Vector length = 62.4 W R (sin $\emptyset_t$ – sin Ø)

Magnitude of vector at Ø = $\emptyset_b$
$\Rightarrow$ Vector length = 62.4 W R (sin $\emptyset_t$ – sin $\emptyset_b$)



Sum vertical forces by integrating over the rotation from $\emptyset b$ to $\emptyset t$

$$= \int_{\emptyset b}^{\emptyset t} 62.4\, WR^2\, (\sin \emptyset_t - \sin \theta)\, (-sin\ \theta)\, d\theta$$

$$= 62.4\, WR^2 \int_{\emptyset b}^{\emptyset t} (\sin \emptyset_t - \sin \theta)(-\sin \theta)\, d\theta$$

$$= 62.4\, W\, R^2 \left[sin\emptyset_t \cos\theta + \frac{\theta}{2} - \frac{\sin\theta \cdot \cos\theta}{2} \right]_{\emptyset_b}^{\emptyset_t}$$

$$= 62.4\, W\, R^2 \left[\left(\sin\emptyset_t\ \cos\emptyset_t + \frac{\emptyset_t}{2} - \frac{sin\emptyset_t \cdot cos\emptyset_t}{2} \right) - \left(sin\emptyset_t\ cos\emptyset_b + \frac{\emptyset_b}{2} - \frac{sin\emptyset_b\ cos\emptyset_b}{2} \right) \right]$$

$$= 62.4\, W\, R^2 \left[\frac{sin\emptyset_t\ cos\emptyset_t}{2} + \frac{\emptyset_t}{2} - \frac{\emptyset_b}{2} - sin\emptyset_t\ cos\emptyset_b + \frac{sin\emptyset_b\ cos\emptyset_b}{2} \right]$$

$$= 62.4\, \frac{WR^2}{2} \left[\sin\emptyset_t\ \cos\emptyset_t - 2sin\emptyset_t\ cos\emptyset_b + sin\emptyset_b\ cos\emptyset_b + \emptyset_t - \emptyset_b \right]$$

Appendix E: PFM Examples

<table>
<tr><th></th><th colspan="2">Example 1 – Embankment Dam FLOOD (Hydrologic Loading)</th></tr>
<tr><td rowspan="4">PFM 1</td><td colspan="2">Summer thunderstorm event, with radial gate closed and flashboards in place, causes overtopping of dam leading to erosion of dam crest and downstream slope leading to failure of the dam</td></tr>
<tr><td>Facts/Conditions:
• PFM study indicates 0.7-ft overtopping
• DSOD 8000-yr flood shows overtopping of 0.6 ft in October and 0.3 ft in April, with gate closed and flashboards in place
• Reservoir level is remotely monitored</td><td>Adverse (likely) Conditions:
1) Crest, downstream slope of dam and abutments are potentially erodible if dam overtops
2) No vegetation cover on downstream slope</td></tr>
<tr><td>Favorable (Unlikely) Conditions:
1) Very short duration of overtopping (<2 hr)
2) Thunderstorm event is a low likelihood event
3) Erosive effects of low overtopping (less than 1 ft) will likely not cause failure of the dam
4) Continuous monitoring of reservoir levels – allows quick response time to raise gate</td><td>Possible Risk Reduction Measures:
• Develop procedure for response during thunderstorm event when reservoir level changes indicate adverse conditions
• Continue to control rodent population in the vicinity of the crest and downstream slope to reduce burrow holes that may cause quicker erosion conditions</td></tr>
<tr><td colspan="2">Classification – Categories II (Not Highlighted), and IV (Ruled Out). Eight (8) participants rated this PFM as Category II since they felt it was important to develop procedures to respond to rapid increases in reservoir levels, and to assess the impact of potential failure of mine ponds upstream of the reservoir. Three (3) participants rated this PFM Category IV. The reason given for this rating is that the overtopping is considered a low likelihood event; the magnitude of overtopping is small, and its duration is short, making it unlikely to cause significant erosion or failure of the dam.</td></tr>
</table>

<table>
<tr><th colspan="3">Example 2 – Embankment Dam FLOOD (Hydrologic Loading)</th></tr>
<tr><td rowspan="4">PF M 2</td><td colspan="2">Under winter PMF condition, with radial gate open and flashboards out, debris/ice flows into the spillway and partially clogs gate openings, causing reduction in spillway capacity and overtopping of dam</td></tr>
<tr><td>Facts/Conditions:
• PMF freeboard is 1.8 ft
• Spillway lengths are 29.7 ft and 14.75 ft.
• Reservoir level is remotely monitored
• Log boom in place</td><td>Adverse (likely) Conditions:
1) Flashboard frame and radial gate frame restrict trash/large debris/ice movement through spillway and are susceptible to clogging
2) Large debris exists along the perimeter of the reservoir
3) Log boom can accumulate large amounts of debris and release all at one time
4) Crest, downstream slope of dam and abutments are potentially erodible if dam overtops
5) Winter access to site is difficult</td></tr>
<tr><td>Favorable (Unlikely) Conditions:
1) During normal operation reservoir is low in winter
2) Log boom exists in front of both spillways
3) 24 hour monitoring of reservoir levels
4) Overtopping is a relatively short event
5) PMF is a low probability event</td><td>Possible Risk Reduction Measures:
• Annually remove large debris from reservoir rim to reduce the possibility of high water transporting material into the gated spillway
• Remove standing dead trees around reservoir rim</td></tr>
<tr><td colspan="2">Classification – Category II, Not Highlighted. All workshop participants rated this PFM as Category II to highlight the importance of taking a proactive approach in monitoring and managing debris in the reservoir.</td></tr>
</table>

<table>
<tr><th colspan="3">Example 3 – Gated Spillway FLOOD (Hydrologic Loading)</th></tr>
<tr><td rowspan="4">PF M 3</td><td colspan="2">During the summer thunderstorm event, prolonged lightening strikes in the area of the spillway prevents operating personnel’s safe access to gate controls, leading to overtopping of the dam abutments, erosion and failure.</td></tr>
<tr><td>Facts/Conditions:
• Gates can be opened quickly (in 5 to 10 min)
• Foundation of dam is on generally massive granitic rock with a potentially erodible fill on the right groin
• Colluvium and artificial fill exists around both abutments
• Dam has experienced a major flood (Jan 2, 1997) of 12,850 cfs
• Gates can be opened about 10 ft
• Left abutment was grouted in 1979 to control leakage
• Operators on-site 24/7</td><td>Adverse (likely) Conditions:
1) No remote operation of gates
2) Access to gates has been limited during thunderstorm events
3) Thunderstorm may lead to quickly changing inflows.</td></tr>
<tr><td>Favorable (Unlikely) Conditions:
1) Operators on-site continuously and can respond quickly to changing conditions
2) Lightning strikes near spillway have been of short duration
3) Lake level and downstream levels are monitored remotely, and continuously</td><td>Possible Risk Reduction Measures:
1) Consider the installation of gate controls located off the dam to allow for safe gate operation during all weather conditions</td></tr>
<tr><td colspan="2">Classification – Category III, More Information Needed. (Vote Tally: I-0, II-0, III-11, IV-0)

Explanation: All participants voted to classify this as a Category III PFM. Participants felt that the Thunderstorm PMF should be determined and a flood routing analysis should be performed before conclusions are reached.</td></tr>
</table>

Example 4 – Concrete Gravity Dam

Potential Failure Mode 4 – Structural failure of spillway gate, Category II

Feature: Spillway gate arm
Loading: Normal, flood, seismic
Description: Previous structural analyses in 2001 and 2007 indicate that capacity of the gate arm columns is less than recommended in current design criteria. The failure mode consists of a structural failure of a gate arm column during operation of the gate due to buckling or overstressing, which is caused by an increase in load due to trunnion pin friction. The failure results in uncontrolled release of the reservoir; however, failure of a gate does not compromise the overall safety of the dam.

Factors Discussed Relative to the Failure Mode	
Positive (does not lead to failure)	**Adverse (leads to failure)**
Standard operating procedures (SOP) include regular (typically annual) testing of all gates to verify that they work properly; SOP also includes testing of the gate hoist systems, guide roller inspection, and washing and painting as needed.	Structural analysis indicates that several gate arm columns do not have adequate strength for the combined axial/bending loads that develop in the members due to trunnion pin friction.
Standard operating procedures include measurement of tension force in gate hoist cables. The cables are adjusted so that tensile load is matched in both right and left hoist cables, to prevent racking of the gate when operated.	New seismic analysis may result in an increase in the earthquake loads. The magnitude is unknown at this time. Gates may require further analysis depending on the magnitude of the earthquake.
Gate No. 8 has new trunnion bearing assembly, which was installed in 2006.	
A program to strengthen the arm columns on 11 of the gates is in progress. The District plans to upgrade (modify) the first gate (Gate No. 9) in 2007-08. The modification to the other gates will follow if the program proves successful. An additional one to two gates are planned to be upgraded each year.	
A gate failure would not cause the dam to fail.	

A gate failure would have low or negligible downstream consequences.	

Potential failure mode categories were voted on by the team members present. Results of that vote and the rationale behind the decisions are presented below.

Category	I	II	III	IV
Votes		11		

Rationale for selected category: Failure of a gate would not significantly increase downstream discharge and is not expected to cause flooding downstream. The District has an excellent set of proactive maintenance procedures to test and verify continued operation of the gates. A plan has been made and is being implemented to strengthen the gates to avoid a gate arm failure due to trunnion pin friction.

Potential risk-reduction measures: The following risk-reduction measures were identified in association with this PFM.

The plan to strengthen gate arms on Gate Nos. 1 through 7 and 9 through 12 should be implemented. These modifications should bring the design of the gates up to current standards and increase the factor of safety against failure.

Example 5 – Concrete Gravity Dam

PFM No. 5 – Gate control malfunction, Category I

Feature: Drum Gate Controls
Loading: Normal
Description: The automated drum gate controls malfunction during the rainy season, causing one or both drum gates to drop (open) uncontrollably. Both drum gates dropping to the full open position would release approximately 10,800 cfs with the reservoir at the normal maximum level (Elev. 1681.2 ft). The rainy season commences on October 1st of each year at which time the drum gates are placed on automatic control. Automated control allows the gate(s) to lower (open) as reservoir levels increases during rainstorms or snow melt and raise (close) as reservoir levels decrease. In the spring/summer after the run-off season, the automatic controls are cut-out to

eliminate the potential for this failure mode to occur. The potential adverse consequence of this failure mode is that the river water level would rise unexpectedly. Anyone near or in the river downstream of the Dam would be at risk of injury or drowning.

Factors Discussed Relative to the Failure Mode	
Positive (does not lead to failure)	**Adverse (leads to failure)**
• Automated control system has been improved based on past events. • System monitored 24/7 from Powerhouse. • Ability to override automated gate operations remotely under some cases. • Short-comings of current system are understood and on-site supervision has been increased during higher risk situations. • Gate control system failure will be slower than PFM No. 2, a sudden failure caused by the intake clogging.	• Control malfunction has occurred in the past. • Prior event raised river level by 14 ft in 45 min. • Capacity of communication systems limit amount of data that can be passed. • Reliability of existing electronics monitoring in dam environment is unknown.

PFM categories were voted on by the team members present. Results of that vote and the rationale behind the decisions are presented below.

Category				
Category	I	II	III	IV
Votes	8	3	0	0

Rationale for selected category: This type of failure has occurred in the past and has a high likelihood of reoccurrence due to the environment in which the gates operate and control systems installed. While the failure process is slow to develop, even a small lowering (opening) of one of the drum gates could produce flows that pose risk to the public safety downstream of the dam. Three members of the group felt that there was sufficient awareness of the PFM, and indicated that corrective measures were currently being implemented that warrant a Category II selection.

Potential risk reduction measures: The following risk reduction measures were identified in association with this PFM:

- Many aspects of the radial gate and drum gate control and communication systems, including lake level, are being upgraded. Work is currently underway in 2005 and is to be completed in 2007.
- Until the reliability of the upgraded system is proven, continue practice of providing additional on-site personnel during critical operations and when storm events are forecasted.

Example 6 – Concrete Gravity Dam

PFM No. 6 – Drum gate failure during flood event, Category II

Feature: Drum Gates
Loading: Flood
Description: During a large flood, the drum gate intake becomes clogged by large debris. The clogged intake prevents water from entering the flotation chambers. The flotation chamber drains continue to function and causes both floating drum gates to quickly drop (open), resulting in an uncontrolled release of water from both gates. The uncontrolled release would increase in the flow and river level downstream of the Dam. However, it is uncertain what the potential adverse consequences would be during a flood event.

Factors Discussed Relative to the Failure Mode	
Positive (does not lead to failure)	**Adverse (leads to failure)**
• High level alarms would have been exceeded. Highway side drum gate begins lowering at 3,500 cfs. • Both drum gates are completely lowered at 30,000 cfs inflow. Major debris movement occurs after 30,000 cfs. • Intake invert located at elevation 1639.7, currently above the sediment line. • Personnel on-site during early stages of flood events. • Major storms are forecasted well in advance, providing time to react.	• Significant debris mobilized during flood events. • No method for monitoring or cleaning grizzly on drum gate intake during flood events.

PFM categories were voted on by the team members present. Results of that vote and the rationale behind the decisions are presented below.

PFM Category				
Category	I	II	III	IV
Votes	0	9	0	2

Rationale for selected category: Debris has entered and clogged the intake to some degree in the past. The current operational procedure calls for the drum gates to be lowered prior to the river flow reaching 30,000 cfs, at which point experience indicates that debris movement begins to occur. Clogging would occur unnoticed until the gate would begin to drop quickly before corrective measures could be implemented. Debris movement is prevalent in this reach of the river, therefore, the PFM cannot be ruled out based on physical impossibility, but the operation procedures merit a Category II rank. Two members of group felt that significant mitigation measures are in place that warrants a Category IV ranking. Specifically, the new intake is located well above the sediment line. They also felt that flood flows are forecasted well in advance so that personnel would be on-site to address clogging issues.

Potential risk reduction measures: No potential risk reduction measures were identified in association with this PFM.

References

American Association of State Highway and Transportation Officials (AASHTO). 2003 Interim. *Manual for condition evaluation of bridges*. 2nd ed. Washington, DC: AASHTO.

American Concrete Institute (ACI). 2008. *Building code requirement for structural concrete*, ACI Code 318. Farmington Hills, MI: ACI.

American Forest and Paper Association (AF&PA). 2005. ANSI/AFandPA NDS-2005 *National design specification for wood construction*. Washington, DC: AF&PA.

American Institute of Steel Construction (AISC). 1953. Historical record dimensions and properties. Herbert Ferris, ed. Chicago, IL: AISC Publications.

———. 2005. *Steel construction manual*, 13th ed. Chicago, IL: AISC Publications.

American National Standards Institute and the InterNational Electrical Testing Association (ANSI/NETA). 2007. *Standard for maintenance testing specifications for electrical distribution equipment and systems*, ANSI/NETA MTS-2007. New York, NY and Portage, MI: ANSI/NETA.

American National Standards Institute/American Society of Mechanical Engineers (ANSI/ASME). 16 January 2007. Standard B30.20-2006. *Below-the-hook lifting devices*. New York, NY: ASME.

American National Standards Institute (ANSI). 2003. Standard MH 27.1, *Specifications for underhung cranes and monorail systems*. New York, NY: ASME.

American Society for Testing and Materials (ASTM). 2005. *ASTM D2240 – 05*. 2010. *Standard test method for rubber property—durometer hardness*. Developed by Subcommittee D11.10. Book of Standards Volume 09.01. West Conshohocken, PA: ASTM.

American Society for Testing Materials (ASTM) D245 – 06. 01 March 2006. *Establishing structural grades and related allowable properties for visually graded lumber*. Developed by Subcommittee D07.02. Book of Standards Volume 04.10. West Conshohocken, PA: ASTM.

American Society of Civil Engineers (ASCE). 1993. *Strength design for reinforced-concrete hydraulic structures*, Technical Engineering and Design Guides as Adapted from the U.S. Army Corps of Engineers No. 2 (reference EM 1110-2-2104). New York, NY: ASCE.

———. 12 May 2010. American Society of Civil Engineers (ASCE/SEI) Standard 7-10. *Minimum design loads for buildings and other structures*. Reston, VA: ASCE.

American Society of Mechanical Engineers (ASME). 1996. *The guide to hydropower mechanical design*. Kansas City, MO: HCI Publications.

———.2010. *Boiler and pressure vessel code*. Section VIII, Division 1, "Rules for Construction of Pressure Vessels." New York, NY: ASME.

American Water Work Association (AWWA). 2005. *Open channel, fabricated-metal slide gates and open channel, fabricated-metal weir gates*. ANSI/AWWA C513-05. Denver, CO: AWWA.

———. 2008. *Hydraulic and pneumatic cylinder and vane-type actuators for valves and slide gates, fabricated-metal weir gates*. ANSI/AWWA C541-08. Denver, CO: AWWA.

———. 2009. *Electric motor actuators for valves and slide gates*. ANSI/AWWA C542-09. Denver, CO: AWWA.

———. 2004. *Fabricated composite slide gates* ANSI/AWWA C563-04. Denver, CO: AWWA.

———. 1992. (rev. 2007). *Specification for cast iron sluice gates* ANSI/AWWA C560. Denver, CO: AWWA.

American Welding Society (AWS). 2008. (Updated annually). *Structural welding code*. AWS D1.1. Miami, FL: AWS.

American Wood Council (AWC). 2005. *National design specification for wood construction*. West Grove, PA: American Forest and Paper Assoc., Inc.

Arkansas Soil and Water Conservation Commission. 1980. *Safety evaluation of small earth dams*. Little Rock, AK: Arkansas Natural Resources Commission (ANRC).

Avallone, Eugene, Baumeister, Theodore, Sadegh, Ali. 2006. *Marks Standard Handbook for Mechanical Engineers*. 11th Edition. London: McGraw-Hill Professional.

Barrows, H. K. 1927. *Water power engineering*. 1st ed. New York, NY: McGraw Hill Book Company.

Brockenbrough, Roger L. 2002. *AISC Rehabilitation and retrofit guide, A reference for historic shapes and specifications*. Design Guide No. 15. Chicago, IL: American Institute of Steel Construction (AISC).

California Occupational Safety and Health Administration (OSHA). August 2000. "Use of rope access equipment." Department of Industrial Relations. Subchapter 7. General Industry Safety Orders Group 1. General Physical Conditions and Structures Article 4. Access, Work Space, and Work Areas §3270.1. http://www.dir.ca.gov/title8/3270_1.html and http://www.ropeworks.com/s.nl/it.I/id.55/.f.

Colorado State Engineer's Office, Division of Water Resources. 1983. *Dam safety manual*. Denver, CO: State of Colorado Department of Natural Resources.

Crane Manufacturers Association of America Inc. (CMMA). *Specifications for top running bridge and gantry type multiple girder electric overhead traveling cranes*. Specification No. 70. Charlotte, NC: CMMA.

Creager and Justin. 1927. *Hydro-electric handbook*. New York, NY: John Wiley and Sons.

———. 1950. *Hydroelectric handbook*. 2nd ed. New York, NY: John Wiley and Sons.

Edwards, W. D., and S. M. Planck. October 1999. Improving the reliability of spillway radial gates. *Hydro Review* 18(6).

Electric Power Research Institute (EPRI). 2004. *Rigger's handbook*. Palo Alto, CA: EPRI.

Federal Emergency Management Agency (FEMA). October 1998 (reprinted April 2004). *Federal guidelines for dam safety: Emergency action planning for dam owners* ("FEMA 64"). Hyattsville, MD: Department of Homeland Security, Federal Emergency Management Agency, Interagency Committee on Dam Safety.

———. 2004. *Federal guidelines for dam safety* ("FEMA 93"). Hyattsville, MD: Department of Homeland Security, Federal Emergency Management Agency, Interagency Committee on Dam Safety.

———. July 1987. *Dam safety: An owner's guidance manual* ("FEMA 145"). Hyattsville, MD: Department of Homeland Security, Federal Emergency Management Agency, Interagency Committee on Dam Safety.

Fenves, Gregory, and Anvil Chopra. August 1987. Simplified earthquake analysis of concrete gravity dams. *Journal of Structural Engineering* 113(8):1688–1708. Reston, VA: American Society of Civil Engineers (ASCE).

Geoffrey L. Kulak, John W. Fisher, and John H. A. Struik. 2001. *Guide to design criteria for bolted and riveted joints*. 2nd ed. Chicago, IL: American Institute of Steel Construction (AISC), http://www.boltcouncil.org/files/2ndEditionGuide.pdf.

Greimann, L., J. Stecker, and M. Nop. September 1995. *Condition rating procedures for tainter dam and lock gates*. Technical Report REMR-OM-17. Champaign, IL: U.S. Army Construction Engineering Research Laboratory, http://www.cecer.army.mil/TechReports/fol_tain/fol_tain.pdf.

Greimann, L., J. Stecker, S. Mellema, K. Rens, and S. Foltz. March 1997. *Condition rating procedures for lock and dam operating equipment*. Technical Report REMR-OM-19, Champaign, IL: U.S. Army Construction Engineering Research Laboraory, http://www.cecer.army.mil/TechReports/fol_doe/fol_doe.pdf.

Greimann, L., J. Stecker, T. Kraal, and S. Foltz. January 1997. *Condition rating procedures for roller dam gates*. Technical Report REMR-OM-18. Champaign, IL: U.S. Army Construction Engineering Research Laboratory, http://owww.cecer.army.mil/TechReports/Fold_Rol/Fold_Rol.pdf.

Greimann, L., J. Stecker, and J. Veenstra. March 1994. *Condition rating procedures for tainter and butterfly valves*, Technical Report REMR-OM-14, U.S. Army Contruction Engineering Research Laboratory, Champaign, IL, http://owww.cecer.army.mil/TechReports/Foltz_OM-14/Foltz_OM-14.pdf.

Institute of Electrical and Electronic Engineers (IEEE). 2007. *National electrical safety code*. ANSI/IEEE C2-2007. New York, NY: IEEE.

Kaltsouni, M., M. J. Morgan, and C. K. Sehgal. 1999. Seismic considerations in the design of gates. In *Waterpower '99 - Hydro's Future: Technology, Markets, and Policy*. Reston, VA: American Society of Civil Engineers (ASCE).

Kentucky Natural Resources and Environmental Protection Cabinet, Division of Water Resources. 1985. *Guidelines for maintenance and inspection of dams in Kentucky*. Frankfort, KY: Kentucky Natural Resources and Environmental Protection Cabinet.

Kyōkai, Suimon Tekkan. 1971. *Technical standards for gates and penstocks*. Tokyo, Japan: Water Gate and Penstock Association.

Mills, George E. 1983. *Operation, maintenance, and inspection manual for dams, dikes, and levees*. Columbus, OH: Ohio Department of Natural Resources (ODNR).

National Fire Protection Association (NFPA). 2011. *National Electrical Code*. NFPA 70. Quincy, MA: NFPA.

———. 2011. Grounding. Article 250. In *National Electrical Code (NEC)*. Quincy, MA: NFPA.

———. 2011. Cranes and hoists. Article 610. In *National Electrical Code (NEC)*. Quincy, MA: NFPA.

North Carolina Department of Environment and Natural Resources (NCDENR). 1985 (revised. 2007). *Dam operation maintenance and inspection manual*. Raleigh, NC: NCDENR, http://www.dlr.enr.state.nc.us/images/DamSafetyManual_rev_20061003.pdf.

North Dakota State Engineer. June 1985. *North Dakota dam design handbook*. Bismark, ND: State Engineer, http://www.swc.state.nd.us/4dlink9/4dcgi/GetContentPDF/PB-77/damdesign.pdf

Oberg, Erik, Franklin D. Jones, Holbrook L. Horton, and Henry H. Reffel. 2008. *Machinery's handbook*. 28th ed. New York: Industrial Press.

Occupational Safety and Health Administration (OSHA). 1998. Regulations in 29 CFR Part 1910, Subpart J, http://www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=STANDARDSandp_id=10121.

———. 1998. Standard 1910.146. "Permit-Required Confined Spaces," http://www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=standardsandp_id=9797.

Pennsylvania Department of Environmental Protection (DEP), Division of Dam Safety. 1986. *A manual for the inspection, maintenance, and operation of dams in Pennsylvania*. Harrisburg, PA: DEP, http://www.elibrary.dep.state.pa.us/dsweb/Get/Document-73604/3140-BK-DEP2139%202009.pdf.

Pilkey, Walter D., and Deborah A. Pilkey. 2008. *Peterson's stress concentration factors* 3rd ed. Hoboken NJ: John Wiley and Sons.

Post-Tensioning Institute (PTI). 2006. Post-tensioning manual. 6th ed. Farmington Hills, MI: PTI.

Schrader, Lawrence F. (ed.). 1979. *Design engineers handbook*. Bulletin 0224-B1. Cleveland OH: Parker Hannifin Corp.4.

Seals Unlimited, Inc., "Rubber Gate Seals, Engineering Information and Product Specifications." Beaverton, OR.

Sorensen, Kenneth E., and Calvin Victor Davis. 1969. *Handbook of applied hydraulics*. New York: McGraw-Hill.

Spector, Leo. July 12, 1984. Hydraulic power units. *Plant Engineering* 38(16).

State of Illinois Department of Water Resources (DWR). 1980. *Guidelines and forms for inspection of Illinois dams*. Springfield, IL: DWR, http://dnr.state.il.us/owr/Publications/ResmanGuidelines_and_ forms_for_inspection.pdf.

STS Consultants. 1985. *Dam safety guidebook*. (Michigan Edition). Lansing, MI: STS Consultants.

The American Society for Nondestructive Testing (ASNT). 2006. *Non-destructive testing*. Recommended Practice No. SNT-TC-1A. Columbus, OH: ASNT.

U.S. Department of the Interior, Bureau of Reclamation Dam Safety Program. 1992. *Guidelines for safety evaluation of mechanical equipment*. Washington, DC: Government Printing Office.

U.S. Department of the Interior, Bureau of Reclamation. 18 November 1996. *Forensic report on spillway gate 3 failure Folsom Dam, American River Division, Central Valley Project California*. Bureau of Reclamation Mid-Pacific Region, Sacramento-California. Washington, DC: Government Printing Office.

———. 1966. Research Report No. 4 *Hydraulic downpull forces on large gates*, Washington, DC: Government Printing Office. http://www.usbr.gov/pmts/hydraulics_lab/pubs/REC/RR04.pdf

———. 1977. *Design criteria for concrete retaining walls*. Washington, DC: Government Printing Office.

———. 1987. *Design of small dams*. 3rd ed. Washington, DC: Government Printing Office, http://www.usbr.gov/pmts/hydraulics_lab/pubs/mauals/SmallDams.pdf.

———. 1988. *Training aids for dam safety module: Inspection and testing of gates, valves, and other mechanical systems*. Washington, DC: Government Printing Office.

———. *Facilities instructions, standards and techniques (FIST) manuals*. Washington, DC: Government Printing Office, http://www.usbr.gov/power/data/fist_pub.html.

———. September 1995. *Special examination review of operation and maintenance program gates 1, 2, 4, 5, 6, 7 and 8 Folsom Dam spillway gates*. American River Division, Central Valley Project California, Bureau of Reclamation Mid-Pacific Region, Sacramento-California. Washington, DC: Government Printing Office.

———. September 1998. *Inspection of brake motors and speed reducers for gate hoists*. Water Operation and Maintenance Bulletin, No. 185. Washington, DC: Government Printing Office.

———. 1988. *Training aids for dam safety (TADS) program*. "Inspection and Testing of Gates, Valves and Other Mechanical Systems," "Identification of Material Deficiencies," "Evaluation of Visual Dam Safety Deficiencies," "Pre-Inspection Activities and Safety, Second Draft," http://www.fema.gov/plan/prevent/damfailure/publications.shtm.

Headquarters, U.S. Army Corps of Engineers (HQUSACE). 31 May 1994. *Design of hydraulic steel structures*. Change 1, Engineering Manual 1110-2-2105, http://140.194.76.129/publications/eng-manuals/em1110-2-2105/toc.htm.

———. 01 August 1966. *Engineering and design, design of spillway tainter gates*. Engineer Manual EM 1110-2-2702. Washington, DC: HQUSACE.

———. 16 January 1990. *Hydraulic design of spillways*. Engineer Manual 1110-2-1603. Washington, DC: HQUSACE, http://140.194.76.129/publications/eng-manuals/em1110-2-1603/toc.htm.

———. 28 February 1999. *Lubricant and hydraulic fluids*. Engineer Manual 1110-2-1424. Washington, DC: HQUSACE, http://140.194.76.129/publications/eng-manuals/em1110-2-1424/toc.htm.

———. 01 December 2001. *Inspection, Evaluation, and Repair of Hydraulic Steel Structures* EM 1110-2-6054. Washington, DC: HQUSACE, http://140.194.76.129/publications/eng-manuals/em1110-2-6054/toc.htm.

———. 30 November 1997. *Vertical Lift Gates,* EM 1110-2-2701. Washington, DC: HQUSACE, http://140.194.76.129/publications/eng-manuals/em1110-2-2701/toc.htm.

———. 02 April 2004. *Lock and Dam Gate Operating and Control Systems* EM 1110-2-2610. Washington, DC: HQUSACE, http://140.194.76.129/publications/eng-manuals/em1110-2-2610/toc.htm.

———. January 2010. *HEC-RAS river analysis system*. Hydraulic Reference Manual. Version 4.1, http://www.hec.usace.army.mil/software/hec-ras/documents/HEC-RAS_4.1_Reference_Manual.pdf.

———. November 1987. *Hydraulic design criteria*. Vicksburg. MS: Coastal and Hydraulic Laboratory, Engineer Research and Development Center Waterways Experiment Station (ERDC-WES), http://chl.erdc.usace.army.mil/hdc.

———. October 1980. *Engineering and design - Hydraulic design of reservoir outlet works*. Engineer Manual 1110-2-1602, 15, http://140.194.76.129/publications/eng-manuals/em1110-2-1602/toc.htm.

Virginia State Water Control Board (WCB), Bureau of Water Control Management. 1983. *Safety evaluation of small earth dams*. Information Bulletin 549. Richmond, VA: WCB.

Westergaard, H. M. 1933. Water pressures on dams during earthquakes. *Transactions ASCE*. Paper No. 1835. 98:418-472.

Wire Rope Technical Board (WRTB). 1997. *Wire rope sling user's manual*. 3rd ed. Alexandria, VA: WRTB.

———. 2005. *Wire rope users manual*. 4th ed. Alexandria, VA: WRTB.

Wyoming Disaster and Civil Defense Office. 1984. *Dam safety: A manual for private dam owners*. Cheyenne, WY.

Zipparro, Vincent J., and Hans Hasen. 1993. *Davis' handbook of applied hydraulics*, 4th ed., New York: McGraw-Hill Inc.

Bibliography

American Concrete Institute (ACI). 1968. Guide for making a condition survey of concrete in service. *Journal of the American Concrete Institute* 65(11). Farmington Hills, MI: ACI.

———. 1982. Materials and general properties of concrete. *ACI Manual of Concrete Practice*, Part 1. Detroit: ACI.

American River Division, Central Valley Project California. 18 November 1996. *Forensic report on spillway gate 3 failure Folsom Dam*. Sacramento, CA: Bureau of Reclamation Mid-Pacific Region.

———. September 1995. *Special examination review of operation and maintenance program gates 1, 2, 4, 5, 6, 7 and 8 Folsom Dam spillway gates*. Sacramento, CA: Bureau of Reclamation Mid-Pacific Region.

American Society of Civil Engineers (ASCE)/U.S. Commission on Large Dams (USCOLD). 1975. *Lessons from dam incidents, USA*. New York: ASCE.

ASME Hydro Power Technical Committee. 1996. *The guide to hydropower mechanical design*. Kansas City, MO: HCI Publications.

Bartholomew, C. L., et al. 1986. *Embankment dam instrumentation manual*. Washington, DC: Government Printing Office.

———. 1987. (To be published) *Concrete dam instrumentation manual*. Washington, DC: Government Printing Office.

Chief of Engineers. 1975. Recommended guidelines for safety inspection of dams. *National Program of Inspection of Dams*, vol 1, Appendix D. Washington, DC: Department of the Army.

Committee on Observations of Dam and Models. 1981. *Automated observation for instantaneous safety control of dams and reservoirs*. Bulletin No. 41. Boston, MA.

Concrete Construction Publication. Inc. 1985. Crack repair. 30(1). Addison, IL: Concrete Construction Publication. Inc.

———. 1983. Four steps to successful concrete repair. 28(1). Addison, IL: Concrete Construction Publication, Inc.

Dunnicliff, J. 1981. *Measurements committee report*. U.S. Committee on Large Dams Section VI, Inventory of Geotechnical Instruments. Denver, CO: United States Society on Dams.

Federal Emergency Management Agency (FEMA). 1984. *Updated review summary of state non-federal dam safety programs*. Washington, DC: FEMA.

Golze, A. R., ed. 1977. *Handbook of dam engineering*. New York, NY: Van Nostrand Reinhold Co.

Graham. W. J. 1983. *Dam failure warning effectiveness*. Denver, CO: U.S. Bureau of Reclamation.

Greimann, Lowell, James Stecker, and Mike Nop. September 1995. *REMR management systems – Navigation structures, condition rating procedures for tainter dam and lock gates*. Technical Report REMR-OM-17. Washington, DC: U.S. Corps of Engineers (USCOE).

Headquarters, Department of the Army (HQDA). 01 August 1966. *Engineering and design, design of spillway tainter gates*. Engineer Manual EM 1110-2-2702. Washington, DC: USCOE, Office of the Chief of Engineers.

Homeland Security. 2007. *Dams sector security awareness handbook*. Webpage, http://www.damsafety.org/media/documents/DownloadableDocuments/DamsSectorSecurityAwarenessGuide_508.pdf.

———. 2008. *Dams sector crisis management handbook*. Webpage, http://www.damsafety.org/media/Documents/Security/DamsSectorCrisisManagementHandbook.pdf

———. *Dams sector protective measures handbook*. For Official Use Only.

Interagency Committee on Large Dams (ICOLD). 1969. *General considerations applicable to instrumentation for earth and rockfill dams*. Boston. MA: ICOLD.

———. 1979. *International conference of building officials uniform building code*. Bulletin No. 41. Boston. MA: ICOLD.

Jansen, R. B. 1980. *Dams and public safety*. Washington, DC: Government Printing Office.

———. 1968. *A prescription for dam safety - Instrumentation and surveillance*. Berkeley, CA: Conference of College of Engineering, University of California.

Mine Safety and Health Administration, Mine Waste and Geotechnical Engineering Division. 1984. *Construction inspection of dams and coal refuse embankments, Bruceton Mills, Pennsylvania*. Washington, DC: U.S. Department of Labor.

National Association of Conservation Districts. *Dam safety - Who is responsible?* Slide show. Washington, DC: National Association of Conservation Districts.

National Research Council, Committee on Safety of New Federal Dams. 1982. *Safety of non-federal dams: A review of the federal role*. Washington, DC: National Academy Press.

———. 1983. *Safety of existing dams. Evaluation and improvement*. Washington, DC: National Academy Press.

———. 1985. *Safety of dams flood and earthquake criteria*. Washington, DC: National Academy Press.

National Research Council. 1982. *Geotechnical instrumentation for monitoring field performance*. Washington, DC: National Academy Press.

Sharma and Raphael. 1979/1981. *General considerations on reservoir instrumentation*. Committee on Measurements. Boston, MA: USCOLD.

Sowers, G. F. 1961. *The use and misuse of earth dams*. New York: Consulting Engineering.

Truby, Jack, and Patricia Hagan. 1985. *The dam failure hazard; Awareness and preparedness*. Golden, CO: Colorado Division of Disaster Emergency Services.

Tschank, Bruce A. 1972. *The inspection and maintenance of privately owned dams in Tennessee*. Knoxville, TN: University of Tennessee.

U.S. Army Corps of Engineers. 1971 and 1976. *Instrumentation of earth and rockfill dams*. Parts 1 and 2, August 1971 and November 1976. Washington, DC: USCOE.

———. 1980a. *Flood emergency plans: Guidelines for Corps dams*. Davis, CA: Hydrologic Engineering Center.

———. 1980b. *Instrumentation for measurement of structural behavior of concrete structures*. DC Washington, DC: USCOE.

———. 1982. *National program for inspection of non-federal dams final report to Congress*. Washington, DC: USCOE.

U.S. Committee on Large Dams (USCOLD). 1983. *Guidelines for inspection of dams following earthquakes*. Washington, DC: Government Printing Office.

———. 1986. *General considerations applicable to performance monitoring of dams*. Boston, MA: USCOLD.

———. *2002. Improving reliability of spillway gates*. Denver, CO: U.S. Society on Dams.

U.S. Department of the Interior (USDOI), Geological Survey. 1985. *Floods from dam failures*. Denver, CO: USDOI.

U.S. Department of the Interior, Bureau of Reclamation. 1974. *Earth manual*. 2d ed., Washington, DC: Government Printing Office.

———. 1975. *Concrete manual, A water resource technical publication*. Washington, DC: Government Printing Office.

———. 1976. *Design of gravity dams*. Washington, DC: Government Printing Office.

———. 1977. *Design of arch dams*. Washington, DC: Government Printing Office.

———. 1977. *Design criteria for concrete retaining walls*. Washington, DC: Government Printing Office.

———. 1982. *Operation and maintenance guidelines for small dams*. Washington; DC: Government Printing Office.

———. 1983. *Safety evaluation of existing dams (seed manual)*. Washington, DC: Government Printing Office.

———. 1984. *Water measurement manual*. Washington, DC: Government Printing Office.

U.S. Department of Agriculture (USDA). 1980. *Forest Service and Soil Conservation Service. Guide for safety evaluation and periodic inspection of existing dams*. Washington, DC: USDA.

U.S. Society on Dams. 2002. *Improving reliability of spillway gates*. Denver, CO: USSD.

Wilson. S. D. 1973. Deformation of earth and rockfill dams. *Embankment dam Engineering: Casagrande Volume*. New York: John Wiley and Sons.

This page intentionally left blank

Index

Page numbers followed by *e*, *f*, and *t* indicate equations, figures, and tables, respectively.