Improving Reliability of Commonly Used Hydraulic Valves

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First Edition

Prepared by the USSD Committee on Hydraulics of Dams
U.S. Society on Dams

Vision
To be the nation’s leading organization of professionals dedicated to advancing the role of dams for the benefit of society.

Mission – USSD is dedicated to:

• Advancing the knowledge of dam engineering, construction, planning, operation, performance, rehabilitation, decommissioning, maintenance, security and safety;
• Fostering dam technology for socially, environmentally and financially sustainable water resources systems;
• Providing public awareness of the role of dams in the management of the nation’s water resources;
• Enhancing practices to meet current and future challenges on dams; and
• Representing the United States as an active member of the International Commission on Large Dams (ICOLD).

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FOREWORD

The United States Society on Dams (USSD) recognizes that with an aging infrastructure, additional demands are being placed on dam owners to ensure safe and reliable operation of their dams. In support of this goal, proper equipment selection, regularly scheduled maintenance, and test-operation of equipment are key elements in determining condition and operational capability of valves. Failure to operate valves upon demand can affect the overall dam safety of a project. The USSD Hydraulics Committee commissioned its Subcommittee on Gates and Valves to develop this technical report as a source of practical experience and information to achieve long-term reliability of valves at dams.

Many types of valves are currently in use or are in the process of being selected and installed at various dam projects around the world. Each valve is selected based on its purpose, hydraulic flow characteristics, operability under normal and emergency conditions, and life cycle costs. Lessons learned tell us that existing valves, which have been worn out by years of operation or have had poor performance records, are being replaced with different types of valves that have shown better performance elsewhere under similar operating conditions.

This report identifies the most common types of valves that have been or are currently being used in dam outlet works and hydropower facilities. It discusses their design features and failure scenarios; makes recommendations with respect to their improved reliability (including inspection and maintenance) and recommends replacement with new and improved types.

Improving valve reliability requires a concerted effort among dam owners, operation and maintenance personnel, designers, and manufacturers. Regardless of an individual’s level of experience or expertise, the depth and breadth of the topics covered in this report can assist anyone associated with dam outlet works or hydropower facilities (including ownership, operation, maintenance, design, and/or regulatory responsibility). Ultimately, the public will benefit from the knowledge provided by this report through improved design and safe operation of water resource projects in their community.

This report was prepared with the combined efforts of many contributors. Dr. B.T.A. Sagar served as the Subcommittee Chairman and main editor of this report. Dan Casapulla and Korey Kadrmas were the primary coordinators and helped edit this report. Report sections were written, in whole or part, by Chander Sehgal, Ed Serfozo, Rejesh Dham, Kishen Prathivadi, Lee Gerbig, Frank Topel, Bernard Peter, B.T.A. Sagar, Dan Casapulla, and Korey Kadrmas. The technical review was performed by James Lindell, Dr. Michael Johnson, Kishen Prathivadi, and Keil Neff. Our thanks are also due to other agencies and individuals for their valuable review and comments. Marty Teal, Chair of the USSD Committee on Hydraulics of Dams, and Jerry Webb, former Chair of the Committee on Hydraulics of Dams, provided overall guidance of this publication. Additional contributing members included other USSD committee members, dam owners, valve manufacturers, and various others in the dam community. Their contributions are gratefully acknowledged.
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**ACRONYMS AND ABBREVIATIONS**

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
</tr>
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<tbody>
<tr>
<td>ASCE</td>
<td>American Society of Civil Engineers</td>
</tr>
<tr>
<td>ASME</td>
<td>American Society of Mechanical Engineers</td>
</tr>
<tr>
<td>AWWA</td>
<td>American Water Works Association</td>
</tr>
<tr>
<td>C</td>
<td>Celsius degree</td>
</tr>
<tr>
<td>CCTV</td>
<td>Closed circuit television</td>
</tr>
<tr>
<td>CFD</td>
<td>Computational fluid dynamics</td>
</tr>
<tr>
<td>CFS</td>
<td>Cubic feet per second</td>
</tr>
<tr>
<td>EPDM</td>
<td>Ethylene propylene diene monomer</td>
</tr>
<tr>
<td>F</td>
<td>Fahrenheit degree</td>
</tr>
<tr>
<td>FEMA</td>
<td>Federal Emergency Management Agency</td>
</tr>
<tr>
<td>FERC</td>
<td>Federal Energy Regulatory Commission</td>
</tr>
<tr>
<td>FKM</td>
<td>Fluoro Rubber</td>
</tr>
<tr>
<td>ft/sec</td>
<td>Feet per second</td>
</tr>
<tr>
<td>GPM</td>
<td>Gallons per minute</td>
</tr>
<tr>
<td>HDPE</td>
<td>High density polyethylene</td>
</tr>
<tr>
<td>ID</td>
<td>Interior Diameter</td>
</tr>
<tr>
<td>JHA</td>
<td>Job Hazard Analysis</td>
</tr>
<tr>
<td>m/s</td>
<td>Meters per second</td>
</tr>
<tr>
<td>NBR</td>
<td>Acrylonitrile-Butadiene</td>
</tr>
<tr>
<td>NEMA</td>
<td>National Electrical Manufacturers Association</td>
</tr>
<tr>
<td>NFPA</td>
<td>National Fluid Power Association</td>
</tr>
<tr>
<td>NPSH</td>
<td>Net Positive Suction Head</td>
</tr>
<tr>
<td>O&amp;M</td>
<td>Operation and maintenance</td>
</tr>
<tr>
<td>OSHA</td>
<td>Occupational Safety and Health Administration</td>
</tr>
<tr>
<td>PTFE</td>
<td>Polytetrafluoroethylene</td>
</tr>
<tr>
<td>Reclamation</td>
<td>U.S. Bureau of Reclamation</td>
</tr>
<tr>
<td>ROV</td>
<td>Remotely Operated Vehicle</td>
</tr>
<tr>
<td>Sq. Ft.</td>
<td>Square feet</td>
</tr>
<tr>
<td>TADS</td>
<td>Training Aids for Dam Safety</td>
</tr>
<tr>
<td>USACE</td>
<td>U.S. Army Corps of Engineers</td>
</tr>
<tr>
<td>USSD</td>
<td>United State Society of Dams</td>
</tr>
<tr>
<td>U/S</td>
<td>Upstream</td>
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<tr>
<td>WES</td>
<td>USACE Waterways Experiment Station</td>
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</table>
CHAPTER 1 – INTRODUCTION

1-1. Background

The purpose of this document is to provide, as available, background information, current state of technology, design considerations and limitations, reliability information, historical performance, and operating equipment information for commonly used water control valves considered for water resources projects.

Several types of water control valves have been installed at many dam and hydropower facilities over the past century. The different types of valves that will be discussed in this report include butterfly, fixed-cone (with and without attached hood), sleeve, spherical, conical plug, plunger, jet-flow, and modified (throttling) knife. The purpose for valves in a piping system includes regulating, flow control, guard, shut-off, energy dissipation, turbine bypass, and emergency closure. Valves traditionally have been used at various facilities such as in dam outlet conduits and powerhouse penstocks.

1-2. Current State of Valve Technology and Research

The technology in the field of valves for dams in the United States is in a state of stagnation as compared to Europe and Japan. Some of the possible reasons may include:

- reduction of dam construction activity in the United States;
- less demand for control valves;
- lack of funding for research and innovations;
- export handicaps due to non-adoption of metric system on a wide scale; and
- limited capability for hydraulic laboratory testing capabilities.

There are several reasons discussed in this paper that illustrate the stagnant state of dam valve technology in United States, and identify where research and development is needed.

For example, butterfly valves have been in use for many decades as guard and emergency shut off valves in penstocks upstream of turbines in hydropower plants where normal flow velocities seldom exceed about 4.5 to 6 meters per second (15 to 20 feet per second). Butterfly valves are also used as guard valves in river outlets where higher flow velocities occur. However, United States valve manufacturers continue to maintain that their valves should not be subjected to velocities exceeding 6 meters per second (20 feet per second) and in some cases even lower velocity limits are suggested. Even high-performance, metal-seated valves may not be suitable for velocities exceeding 9 meters per second (30 feet per second). The result is that designers must enlarge conduit diameter and use larger diameter valves, necessitating upstream and downstream transitions; which increase capital costs significantly.
It is the opinion of the authors of this report that the valve industry should be able to develop a butterfly valve suitable for high velocity flows even in the order of 18 meters per second (60 feet per second). At Pantabangan dam in the Philippines and Wadaslintang dam in Indonesia such valves have been subjected to velocities exceeding 21 meters per second (69 feet per second) in actual installations and have been successfully operating for over ten years.

In recent years, flow-through or biplane butterfly valves have become popular for use in penstocks, as they have less head loss and less operational torque requirements as compared to the lentil-shaped valve discs. However, the United States hydro industry has been reluctant to use them in free-flow high-velocity outlets. For Batitegi dam outlets in Sumatra, Indonesia, hydraulic laboratory tests conducted at the University of Graz in Austria conclusively demonstrated not only that biplane valves can be used safely in high velocity outlets as guard valves; but that they have superior hydraulic performance as compared to standard lentil-type butterfly valves. Biplane butterfly valves are in operation in the outlet works at Wadaslintang Dam and Batutegi Dam for velocities exceeding 15 meters per second (50 feet per second). United States designers and valve manufacturers should be able to meet such high-velocity flow with proper streamlining to minimize flow obstructions and application of advanced design techniques to the valve passages.

Also, United States designers and valve manufacturers lag behind their European counterparts in the development of inline, high head, and energy-dissipation valves. Generally, high-head conditions are assumed when the hydraulic head is greater than about 15 meters (50 feet). Multiport sleeve valves have been developed to dissipate energy while controlling discharge. As compared to valves used in the United States, valves developed in Europe are rather compact, perform cavitation free, and need less operational force. European manufactured valves are operating satisfactorily in several installations in United States dissipating 60 meters (200 feet) of energy. However, the above high head butterfly valves tend to have clogging problems due to grit and other coarse materials necessitating need improvements.

An area which requires further research is the determination of minimum safe distance between the butterfly valve and the control valve located downstream of the butterfly valve. According to the experiences of Dr. Sager, Henry Falvey, and other paper contributors, a few decades ago, fixed-cone valves in some installations experienced vane failures under prolonged operation when located downstream of conventional butterfly valves (Falvey, 2004 and Gerbig, 2004). A possible cause could have been the thinness of the fixed-cone valve vanes, but these particular failures were attributed to the location of butterfly valves. The proximity of the butterfly valve to the fixed-cone valve did not provide adequate distance required to stabilize the flow disturbances downstream of the butterfly valves. A rule of thumb has been in place since these failures that requires a minimum distance of five to six conduit diameters between the butterfly valve and downstream control valve. Many valve manufacturers insist upon this rule of thumb regardless of the type of butterfly or gate valve or the type of control valve located
downstream. This rule of thumb may be resulting in unnecessarily longer lengths of outlet conduit and significant extra costs due to oversized valve house structures.

In the recent years the vane thickness of the fixed-cone valves has been substantially increased based upon Mercer’s formula (Mercer, 1970) and no recent vane failures have been reported. It has been demonstrated that flow past biplane butterfly valves will stabilize in a much shorter distance downstream than flow past lentil type butterfly valves. Also, flows past butterfly valves obviously cannot cause damage to rather rigid valves like plug valves or gate valves or to the slide or jet-flow gate valves. Further research is needed to establish minimum safe distance between butterfly valves and various types of downstream flow control valves to avoid disputes and eliminate needless extra costs.

Problems encountered with valves under various operational scenarios have traditionally not been publicized or documented. The result is that different opinions expressed by hydraulic flow experts and/or valve suppliers are often contradictory or unsubstantiated. Additional research and testing is needed to prove or disprove the following:

- Butterfly valves should not be used for throttling or regulating the flows for heads exceeding 15 meters (50 feet).
- Traditional fixed-cone valves are not suitable for submerged discharge, as they will have severe cavitation damage. However, there are some instances of fixed-cone valves designed for submerged conditions such as New Castle Dam in California and Logan Hydro No. 2 in Utah according to Dr. Michael Johnson.
- Spherical valves, not butterfly valves, should be used as guard valves for high heads exceeding 200 meters (1200 feet).

These opinions and/or theories need to be supported by scientific research by the valve industry and/or hydraulic design organizations, which may lead to developments improving valve performance and solutions to field flow problems.

The above paragraphs are intended as a challenge to valve manufacturers and design organizations and emphasize the need for vigorous research and development as well as improvements to existing designs to achieve not only technological advancement, but also to improve reliability and performance of various types of valves currently in use.
CHAPTER 2 – TYPES OF VALVES

2-1. Introduction

Throughout the years, many types of valves have been used in the outlet works and hydraulic facilities of dams worldwide. Selection of the appropriate valve for water control applications requires consideration of several factors; including hydraulic head, discharge quantity, spray, permissible degree of regulation, and type of energy dissipation necessary beyond the point of regulation. Other considerations that may affect valve selection are the conduit configuration, air venting requirements, and the physical limitations dictated by the outlet works location. The focus of this chapter is to provide a general discussion on the most commonly used valves for water control purposes; such as flow regulation, flow control, guard, shut-off, emergency closure, bypass, or free-discharge at a dam or powerhouse.

2-2. Commonly Used Valves

a. General

A valve is a mechanical device that controls the rate of flow of a liquid through an enclosed conduit. A valve has the ability to function for a variety of purposes; including regulating (“throttling”) flow rates, isolating flow (“guard” or “shut off” valves), energy dissipation, or a combination of these purposes. Regulating valves, for purposes of this report, will include flow control and energy dissipating valves; and shut-off valves will include guard and emergency closure valves. The most common types of regulating valves currently in use and included in this report are fixed-cone (with or without stationary hood), fixed-cone with attached hood, sleeve, plunger, jet-flow, and modified (throttling) knife. The most common types of shut-off valves currently in use and included in this report are butterfly, spherical, knife gate valves, and conical plug. Modern valves are designed to be simple and rugged; they are used for water control because of proven reliability and performance history.

Design of valves for energy dissipation can be very complicated and may require extensive model testing for the use at dams and other hydraulic facilities with similar discharge structures. A technical manual titled Outlet Works Energy Dissipators – Best Practices for Design, Construction, Problem Identification and Evaluation, Inspection, Maintenance, Renovation, and Repair was prepared by a group of nationally recognized engineers to provide best practices information on energy dissipators for outlet works (FEMA, 2010). The technical manual promotes greater consistency between similar project designs, facilitate more effective and consistent review of proposed designs, and aid in the design of safer, more reliable facilities.
The following characteristics are specific to regulating valves:

- control flow in or out of a conduit/conduit, and are generally found in low level or mid-level conduits, in penstocks, and in direct discharge or bypass lines;
- can be installed at the inlet, outlet, or an intermediate position in a conduit, as long as the air demand requirements are satisfied;
- usually, because of high air demand, fixed-cone valves, and sleeve valves, and jet-flow gate valves are used at the outlet end for free discharge;
- ability to operate in any position: fully open, partially open, or fully closed; and
- ability to be opened and closed against flow.

The following characteristics are specific to shut-off valves:

- protect and ensure a watertight shutoff of the conduit;
- operated only in fully open or fully closed position;
- may be used at inlet, in an intermediate position, or as a guard valve located immediately upstream of a regulating valve;
- normally are opened and closed under a balanced water condition; and
- designed for closure against full-head flow in an emergency.

The following characteristics are common to both regulating and shut-off valves:

- Fluid cannot be allowed to leak into the environment.
- There is no internal leakage. When the valve is closed there can be no flow, either along the normal fluid path or between valve parts, where flow is never intended.
- All valve types are manufactured with ends that mate with the common piping connection methods: such as threaded, flanged, butt-weld, socket weld, and grooved. Some valves are made with no ends. There are two different styles, wafer valves and lug valves, both of which are designed to be used with flanges. The wafer style is used between mating flanges. The lug style valve has lugs with threaded holes spaced around its perimeter.
- When a valve is fully open, the ideal valve would offer no more flow resistance than would an equal length of conduit.
- When a valve is fully closed, the ideal valve would permit no fluid to pass.
- Resist distortion by internal fluid pressure and by loads from connected piping.
- Resistance to dynamic effect of fluid, such as temperature, pressure drop, vibration, corrosion, erosion, and damage from objects in fluid stream.
- Smooth operation and movement of valve operating components.

b. Design

The design of a valve must consider the need for containment of fluid pressure forces from the fluid and must resist distortion from fluid forces and physical loads applied. Also, the valve must have the ability to prevent internal or external leakage. Valves are constructed of several materials classified as either metal or nonmetal and are required to
adhere to industry standards. The design of a valve and selection of component materials and strengths depends on the hydraulic head and pressure design requirements. In general, valve components consist of a body, bonnet, stem, disc (or wedge), and actuator. A detail of typical valve components with a manual actuator is shown on Figure 2.1.

Figure 2-1. Typical Valve Components (Courtesy of http://wermac.org)

The body of a valve consists of a framework that houses the fluid control device and all ancillary components. It must be designed to withstand fluid pressures from connecting conduits, support the actuator, and resist actuator forces during valve operation. Body shapes vary for each different type of valve and application; however, the body must be shaped to allow for easy installation and maintenance of valve components.

The bonnet provides a water-tight seal for the valve body. Typically, the actuating stem runs through the bonnet. The bonnet can be attached to the valve body in a variety of ways. The most common method of attachment is to screw the bonnet directly to the body, forming a tight seal. In high-pressure applications, the bonnet can be screwed to the body of the valve. A key component of a bonnet is the packing, which maintains the seal between the bonnet and stem. The stem transmits motion from the handle or controlling device to the disc. The motion transmitted by the stem may be linear and/or rotational.
The disc consists of the valve component that is used to block the passage of flow and provide a water tight seal. Disc shapes vary with each type of valve, but typically consist of a sphere-shaped object or a flat plate. Discs abut to the ring seats in the valve body to form the water-tight seal. See Figure 2-2 for an example of a butterfly valve and Figure 2-3 for a cross section view of a typical valve body.

![Figure 2-2. Image of a typical butterfly valve (Courtesy of Rodney Hunt Valve)](image)

![Figure 2-3. Typical Flanged-End Butterfly Valve Section (Courtesy of www.pipingguide.net)](image)
Valves whose disc is between the seat and stem and where the stem moves in a direction into the valve to shut it are normally seated or front seated while valves whose seat is between disc and stem and where the stem moves in a direction out of the valve to shut it are reverse seated or back seated.

c. Loss Coefficients

Valves are used to regulate or control flow and/or pressure by operating partly to fully open. The internal flow (hydraulic) impacts of a valve along an outlet works or penstock is that a localized flow disruption is created with varied head losses and pressure differentials depending on the valve geometry and influence on velocity profiles. Discharge rating curves are developed for hydraulic operating systems and an understanding of energy and pressure loss potential of the piping components is necessary for proper operation and understanding of system performance. System losses may be presented as an equivalent pipe diameter length that approximates valve energy loss in terms of “x” many diameters of straight pipe of comparable energy loss at the same flow rate; however, this method is an approximation and friction and component losses vary differently with the Reynolds number. The preferred method is a single system loss coefficient defined as the non-dimensional difference in total pressure between the ends of an assumed long straight pipe with no other loss components (Miller, 1990). The headloss (h, feet) for a valve is measured by the following equation:

\[ h = \frac{K \cdot V}{2g} \]  
(Equation 2.1)

Where: 
\( K \) valve loss coefficient
\( V \) velocity in the approach piping area (feet per second)
\( g \) represents acceleration due to gravity (32.2 m/sec\(^2\))

Valve loss coefficients can be provided from the manufacturer. Table 2.1 lists recommended energy loss coefficients (“K”, dimensionless) for fully open common valves (Mays, 2010) for design and layout purposes. Typical loss coefficients for fully open valves are plotted against valve seat/pipe diameter for different valve types (Miller, 1990).

<table>
<thead>
<tr>
<th>Valve Type</th>
<th>K</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ball</td>
<td>0.04</td>
</tr>
<tr>
<td>Butterfly (150-lb Class)</td>
<td>0.35</td>
</tr>
<tr>
<td>Cone</td>
<td>0.04</td>
</tr>
<tr>
<td>Diaphragm or Pinch</td>
<td>0.2 – 0.75</td>
</tr>
<tr>
<td>Fixed-Cone Valve (No Hood)</td>
<td>N/A(^{(1)})</td>
</tr>
<tr>
<td>Fixed-Cone Valve (With Hood)</td>
<td>N/A(^{(1)})</td>
</tr>
<tr>
<td>Gate</td>
<td>0.1 – 0.3</td>
</tr>
<tr>
<td>Knife Gate (metal/resilient seat)</td>
<td>0.2/0.3</td>
</tr>
<tr>
<td>Plug</td>
<td>0.5 – 1.0</td>
</tr>
</tbody>
</table>

Note: (1) The Miller, 1990 reference does not referenced fixed cone valves (see text below).

Table 2.1 Recommended Energy Loss Coefficients for Fully Open Common Valves
Fixed-cone valve manufacturers typically do not report energy loss coefficients, as noted in the Miller, 1990 reference above. According to Dr. Johnson of Utah St, a constant K value normally does not apply for fixed-cone valves. The typical measured coefficient value for a fully-opened fixed cone valve with integral hood (ring-jet valve) is 0.78 and without hood is 0.85 and are used in the $Q=Cd*A*\sqrt{2*g*Ht}$ equation. A fixed stationary hood does not reduce the discharge coefficient. The fixed-cone valve is not a typical in line valve like the others listed above. The discharge coefficient for a fixed-cone valve should be tested and reported for the full range of valve operation. Utah State has tested fixed-cone valves manufactured by Hilton and the testing has shown that the Cd value is unchanged for hooded versus unhooded valves (Tullis, 1989).

d. Actuators

Actuators and hoists are the mechanisms used to control the position of the disc. Power systems available for operation of a valve can be manual, electric, hydraulic, or pneumatic. Actuators can range from simple manual hand-wheels to sophisticated automated controls by computer “actuators” that have programmed controls.

An actuator consists of the device that is used to move the valve disc that controls the flow within the valve based on converting energy into torque and thrust. Typically, actuators are classified as either mechanically-powered (manual), hydraulic-powered, electric-powered, or electrohydraulic. For mechanically operated valves, the actuator usually consists of a hand-wheel and lever. The hand-wheel is connected to the stem and is used to open or close the disc. Assisted actuation is accomplished with mechanisms that can be used to convert fluid or electrical energy to operate the valve disc. Hydraulic actuators can be used for large applications (large valve size or high pressure) or where site conditions restrict access to a mechanical actuator. Hydraulic actuators use cylinders to open or close the valve disc. Electric actuators are operated by electric motors with gearing to create the necessary torque to open and close the valve via a valve stem. The electrohydraulic actuator combines the electrical and mechanical parts including an electric motor, hydraulic pump unit, and a hydraulic cylinder.

2-3. Selection

Valve selection is generally based on:

- Intended purpose
- Hydraulic flow concerns
- Previous performance
- Operability under normal and emergency conditions.
- Hydraulic head
- Discharge quantity
- Allowable spray
- Permissible degree of regulation
- Type of energy dissipation
- Life cycle costs
Butterfly valves, rather than spherical or plug valves, are more commonly used as guard or non-regulating emergency closure valves if the greater head loss associated with flow through a butterfly valve is not a concern. Fixed-cone valves have been the most common type of valve used for flow regulation and energy dissipation. A hood can be attached directly to the fixed-cone valve or installed in a separate structure, where necessary to contain the discharge spray and protect the surrounding structures. Sleeve valves are used for the same purpose except that their discharge is submerged; therefore requiring no hoods. Jet-flow gate valves and modified knife gate valves use a short discharge conduit to contain the flow. Needle and tube valves previously used for free-discharge applications have had cavitation problems and therefore are no longer being installed and will not be addressed in this report. Where the currently installed needle or tube valves need replacement, they are being replaced with fixed-cone, plunger, or sleeve valves.

**2-4. Valves Not Recommended**

Needle, tube, and hollow-jet valves (Figure 2-4) are no longer recommended for the following reasons:

- high life cycle costs;
- less hydraulically efficient;
- needle slamming closed causing waterhammer (on water-operated needle valves);
- instability of the discharge jet causes vibration and uneven spray (tube valves only);
- cavitation and waterhammer concerns;
- need to be disassembled every 2 to 6 years to remove accumulated scale, (depending on the water quality);
- need, in some installations, to drain the water completely from the valve control chambers and refill with oil to avoid inability to operate the valve;
- susceptible to internal corrosion, seat erosion, cavitation damage, and general maintenance difficulties;
- seat erosion at small openings;
- potential for cavitation damage at any slight offsets in the downstream bodies; and
- high fabrication costs because of the complex shapes used in the needle portion and upstream body.
2-5. Cause and Avoidance of Valve Problems

a. General

There are several causes of valve malfunctions and failures and operational considerations to avoid for proper valve and system operation to minimize valve problems. Measures will be presented in this section for consideration that can be used to prevent or reduce the number of failures and a discussion is provided regarding cavitation concerns related to valve design and flow system performance. Detailed discussions are provided in each valve chapter of specific design and/or operational considerations to avoid for proper valve and system operation.

Causes of valve malfunction and failure include:

- Debris
- Cavitation
- Ice
- Operator error or lack of training
- Malfunction of operating mechanism
- Lack of exercise
- Deterioration and corrosion
- Use of obsolete equipment
- Inadequate air supply
- Improper installation
- Lack of formal inspection program
- Inadequate maintenance, testing and inspection
- Out of date or lack of operating manuals
- Improper valve for the application
b. Shift in Point of Flow Control

A major concern in valve operation at outlet works is a shift in the point of flow control. Points of flow control occur when fluid springs free from an edge of a valve disc or passes through a constricting area within an outlet conduit. As long as fluid flow past any given point of control is stable there is typically no problem with operation of an outlet works. If control of fluid flow oscillates from one point of control to another within a conduit system, pressure fluctuations and surges in the flow may result in flow-induced vibration that could be a problem to long-term safe operation of an outlet works. From a practical standpoint, the most advantageous system configuration would maintain the control point at the downstream end of the conduit system throughout the anticipated range of valve operation.

An example of shift in the point of flow control occurred at Platoro Dam outlet works in South Central Colorado. The structure contained about 387 feet (118 meter) of 56-inch-diameter (1.42 meter) ID steel conduit. The conduit branched through a Y-shaped bifurcation on the downstream end to two 48-inch-diameter (1.22 meter) butterfly valves. In testing the vibration of the system, it was obvious that with openings of 82% or larger, control had shifted to the upstream conduit. The flow areas and friction are assumed to be the governing factors.

The 56-inch (1.42 meter) ID conduit has a flow area of 17.10 sq. ft. The flow area through the butterfly valves is dependent on the disc - shaft - seat configuration which is not known. Based on nominal (i.e. 48-inch) each valve would have an area of 12.57 sq. ft. or 25.13 sq. ft. total, much larger than the 56-inch (1.42 m) ID conduit. With the use of an accelerometer, the 82% openings were located. A safe value of 74% was initially selected. Subsequent tests showed that the openings could be safely increased to 78%.

In addition to flow area, the influence of friction and minor losses would have the most influence on flow control and a hydraulic analysis is required to identify where control issues may exist and could shift.

Additional examples of shift in point of flow control are provided in Chapter 4 Fixed-Cone Valves.

c. Measures to Prevent or Limit Failure

Measures that can be used to prevent or reduce the number of failures include the following:

- proper application of valve for the installation;
- proper training of all operations and maintenance personnel;
- regular periodic exercise of all valves to prevent corrosion buildup on seats and other moving parts that would inhibit operation (minimum of once per year, preferably 3 or 4 times per year);
- note any unusual noises or vibration during operation of equipment;
• inspect all equipment to determine cause of noise or vibration and/or damage to equipment;
• periodically measure electrical current to the valve actuator or hydraulic cylinder pressure for comparison with previous measurements (to note any deviations);
• replace outdated and unreliable valves and operators with current technology;
• provide redundancy for critical components;
• develop and maintain an inspection program (see Appendix B);
• simplify design configuration of the outlet conduit (minimize elbows, contractions; expansions, bifurcations, etc.); and
• restrict sudden closure of shut-off valves (to avoid waterhammer).

When performing design of new outlet works or outlet works rehabilitations, a mechanical or civil engineer, experienced with the design of valves and mechanical systems for dam outlet works, should review and approve the design.

d. Cavitation

Cavitation is a concern to valve design and flow system performance since excessive flow cavitation could cause flow instability and lead to restriction of flow capacity and/or catastrophic damage to the piping system. Typically, capacity is only reduced when choking cavitation is present and prior to this happening, there would likely be damage to either the valve or associated piping. Only a few valves claim to be cavitation damage free, but generally all valves require evaluation of cavitation conditions as part of the valve component and/or system design. This section provides technical background regarding flow cavitation that should be considered when evaluating cavitation potential of selected valve components. Critical cavitation discussions specific to each type of valve are provided in corresponding chapters of this report.

Cavitation is the sudden vaporization and condensation of a liquid at or downstream of the valve due to large pressure drops across the valve, which typically occurs in an outlet works piping system that exhibit sufficiently large pressure drops that cause localized high flow velocities. When a localized low pressure area falls below the vapor pressure of the fluid, the liquid vaporizes and forms a water vapor pocket (bubbles or cavities). As the vapor pocket flows downstream into conduit regions where the pressure recovers (higher static pressure zones), the vapor becomes unstable and violently condenses (collapsing the bubbles and cavities) causing a popping or rumbling sound. Several references describe the sound ranging from the occasional “popping” at the onset of cavitation, to a sound similar to that of frying bacon as cavitation is building, and when cavitation becomes potentially catastrophic it may sound like gravel passing through the conduit.

Although cavitation is usually detrimental, turbulence in fluid flow caused by cavitation can potentially be beneficial in mixing fluid or cleaning internal conduit surfaces. Typically, cavitation is a transient phenomenon that occurs at a valve that is initially “cracked” opened and experiences full system hydraulic head with high localized flow velocities. This phenomenon is typically unavoidable and occurs for short periods;
however, the valve and associated piping system should be designed to withstand some cavitation and its corresponding flow impacts. The acceptable cavitation mechanism is for vapor cavities to collapse within solution before being transported to the solid boundary of the pipe, valve or seat causing erosion damage. If the system achieves cavitation formation where erosion damage occurs, the erosion damage will increase rapidly as the localized velocity increases.

In pipe systems where flow separation regions occur; valves, conduit piping, and non-uniform conduit sections have the potential to induce small cavitation bubbles to form on the boundary walls and in the area of localized high velocity flow there is the potential for the water vapor bubbles to diffuse from solution followed by a segment of pipe system that exhibits static pressure recovery. Occasionally, large bubbles may form in these regions potentially producing the aforementioned cavitation sounds. This process is due to the presence of dissolved gas (free gas) in the liquid that is crucial to the gaseous cavitation process, since without this gas the liquid would not be able to withstand large tension forces without rupture. This process is termed “gaseous cavitation” and according to Tullis et al occurs when there is either considerable free air suspended in the liquid or when the cavitation process is slow enough to increase the amount of air inside the vapor cavity due to degassing from the liquid (Tullis, 1989). However, gaseous cavitation occurs if there is little air in the liquid with the cavity comprised almost exclusively of vapor. For this process the growth and collapse rates of the cavity and the pressures generated upon cavity collapse can become extremely high and may cause severe damage. Due to the presence of free air the rate of growth and collapse of the cavity is slower for gaseous cavitation so the process is not as violent or damaging. Free gas can be present in fluid in the form of microscopic bubbles and in surface crevices of particles carried in the fluid (Miller, 1990).

Outlet works piping system have defects on internal valve bodies, conduit walls, and ancillary equipment internal surfaces with “pits” or surface deviations that become filled by air voids or bubbles. Bubble dynamics and air-water flow relationships in hydraulic structures were extensively evaluated by Dr. Henry T. Falvey to establish an understanding of air entrainment and air-demand for open- and closed-conduit flow conditions. The research was used to develop procedures for air vent sizing for outlet works and spillways and to support additional hydraulic research areas (Falvey, 1980). Additional documentation was developed by Dr. Falvey for the purpose of giving hydraulic structure designers an understanding of cavitation and the design tools necessary to eliminate or reduce the damage effects of cavitation (Falvey, 1990). Cavitation can be induced within a piping system by the following surfaces:

- valve internal control points;
- conduit diffusers, bends, piping specials, and slots;
- conduit internal surface cavities/discontinuities; and
- orifices/nozzles.

Cavitation must be considered for valve design, since a valve experiencing cavitation may potentially reduce the flow capacity within the piping system, impact the operational
range of the valve, and possibly cause catastrophic damage to the valve and/or piping
system. The extent of cavitation varies with valve type, size, operating pressures, and
installation or piping details. Valve designers must consider the degree of cavitation
potential over the full operational range of the valve and determine if cavitation potential
is great enough to cause erosion damage and if so determine a design solution. The
following critical definitions that quantify cavitation potential are used to design valves
and piping system components such as establish cavitation parameter valves, component
geometry and sizes, and head loss coefficient (Miller, 1990):

- **Incipient Cavitation** (onset of cavitation - intermittently) – No objectionable noise
  and there is no damage, except at localized areas such as over a small step or a
  roughness element.
- **Constant (or Critical) Cavitation** (continuous light cavitation) – Noise and
  vibration are acceptable, and only minor damage can be expected after long
  periods of operations (months to years). Typically adopted as a design criteria
  and for most applications critical cavitation is considered relatively safe operating
  limit (Johnson, 2000 and Tullis, 1993).
- **Incipient Damage** (onset of surface pitting after short periods of operation) –
  Noise level may be objectionable.
- **Choking Cavitation** – This is the condition at which the outlet pressure of the
  component is lowered to the vapor pressure and flow through the component is
  unaffected by the downstream pressure condition (steady state pressure, flow, and
  pressure loss relationships no longer apply). Noise and vibration reach a
  maximum when close to “choking” and then decrease.
- **Supercavitation** – This condition occurs if, after choking, the upstream pressure is
  increased or the downstream pressure decreased resulting in the cavity collapse
  region moving increasingly further downstream, causing noise, vibration, and
  damage to the downstream parts of the system.

The extent of cavitation for a piping system is quantified by a non-dimensional cavitation
parameter. The cavitation parameter is based on the mean flow velocity within the
conduit and is a ratio of the forces suppressing cavitation to the forces causing cavitation.
The cavitation parameter is defined by the following equations (Miller, 1990):

\[
\sigma = \frac{h_u - h_v}{u^2/2g} \quad \text{(Equation 2.2)}
\]

where:
- \(\sigma\) Cavitation parameter (dimensionless)
- \(h_u\) Upstream head at inlet – generally 2x Dia. u/s length
- \(h_v\) Vapour head at inlet temperature (length)
- \(U\) Flow velocity through component (length per time)
- \(g\) Gravitational acceleration (length per time squared)
- \(h_d\) Head measured at minimum 10 diameters downstream
  of component (length)

or

\[
\sigma = \frac{h_u - h_v}{h_u - h_d} = \frac{h_u - h_v}{\kappa U^2/2g} \quad \text{(Equation 2.3)}
\]
The cavitation parameter is also referred to as the Thoma Cavitation Factor (Number) for pump and turbine design. The parameter theory is similar for both methods; except, the Thoma Factor is calculated as the net positive suction head (NPSH) divided by the pump or turbine available head. For the purposes of this report cavitation will be referenced by the cavitation parameter (Baran, 2007).

The majority of all cavitation data is obtained experimentally, typically with reduced size physical models operated at reduced pressures and velocity. If not reproduced similar to the geometry, dynamics, and fluid properties of the installation condition, then the experimental data may not accurately represent the performance of the prototype (Tullis, 1989a). Scaling refers to extrapolating data from one condition to another assuming complete similarity. However, there are scale effects due to discrepancies between models and prototypes. Experimental data for valves have shown significant scale effects due to increased velocity, pressure, and size. Due to these scale effects, the cavitation parameter does not have unique values even for geometrically similar components tested with the same fluid (Miller, 1990). For this reason, caution should be used in cavitation analyses and these assessments should be evaluated on a case-by-case basis. If there are significant differences in the fluid properties between the fluid used in the laboratory and the prototype then errors may result; however, if fluid properties can be held generally constant then the cavitation parameter relationships will produce reliable results for various cavitation conditions.

The potential for valve cavitation can be typically estimated through one or more of the following sources according to Miller (1990):

(a) establishing design criteria,
(b) developing laboratory data for valves,
(c) applying scale effects associated with each cavitation design limit, and
(d) utilizing examples to demonstrate the application of the data.

There are the following mechanisms for suppressing cavitation and reducing or eliminating such damage to a valve or piping system (Tullis, 1989b):

- Restrict the operation of the system to a low level of cavitation such that the cavitation formation does not contain much energy and collapse before reaching the surface boundary.
- Removing the boundary from the cavitation zone such as using a sudden enlargement, which will dissipate energy while suppressing cavitation; however, this increases the head loss within the system.
- Treating the surface with a material more resistant to cavitation erosion. Typically, it is common to line certain parts of valves, pumps, and turbines with stainless steel or other erosion resistant materials or coatings; however, this solution is usually expensive and may not be cost effective.
- Introducing air into the separation region to supersaturate the critical region with air and greatly reducing the bulk modulus of the liquid and cushioning the collapse of the cavities by reducing the wave speed and reducing or
eliminating the erosion damage. Typically, this is the most common and
effective mechanism

- Dissipate the energy in stages throughout the piping system by locating
multiple valves or orifices in series; however, this method tends to be more
expensive and requires evaluation of the cavitation potential and required
reduction at each stage.
CHAPTER 3 — BUTTERFLY VALVES

3-1. Application

A butterfly valve is a cylindrical valve with a rotating disc that blocks the cross sectional area of the conduit. Butterfly valves are commonly used at hydropower plants and dam facilities. At hydropower plants, butterfly valves have been used as the guard and emergency shut-off valves upstream of the turbines, where normal flow velocities seldom exceed about 4.5 to 6 meters per second (15 to 20 feet per second). A butterfly valve has a circular body with a circular disc that rotates on a shaft at the diametrical centerline of the valve. Although some valves are installed with the shaft vertical, most are installed with the shaft horizontal. The disc can be solid (Figure 3-1) or flow-through type (Figure 3-2) and is always parallel with the flow of fluid when the valve is full open. The disc is rotated approximately 90 degrees from open to closed position by an operator connected between the shaft and the exterior of the valve body.

![Figure 3-1. Typical “Solid” Biplane Butterfly Valve (Courtesy of Dr. BTA Sagar)](image1)

![Figure 3-2. Butterfly Valve with Flow Through Disk Design (Courtesy of Pratt Industrial)](image2)
The advantages of selecting butterfly valves are drip-tight shutoff capabilities, ease of operation, little maintenance, low cost, low head loss, reliability, small space requirements, and possible throttling capabilities. The disadvantages for selecting butterfly valves are limited flow control capabilities, flow interference by the disk, and systems that require additional head loss. In summary, butterfly valves are relatively inexpensive to purchase, install, and maintain; so butterfly valves are widely used in a variety of installations if additional head loss and turbulence through the valve are not a concern.

Butterfly valve manufacturers provide cast or fabricated body and disc options. The body styles typically include flanged or mechanical joint ends. Also, the seat/seal may be located in either the body or on the disc depending on the manufacturer. Butterfly valves provide space-saving benefits compared to other types of valves and are typically corrosion resistant since generally the valves require minimal long-term maintenance.

3-2. Sizes and Heads

Most butterfly valves used today are small to medium sized, are commercially designed and manufactured, and are purchased from a catalog. Butterfly valves for use with higher heads up to 1034 kPa (150 psi), and in larger sizes, up to 1.829 meter (72 inch), are commonly designed and manufactured in accordance with the standards developed by the American Water Works Association (AWWA). The corresponding AWWA Standard is C504 and covers rubber-seated butterfly valves, 0.075 meter (3 inch) through 1.8 meter (72 inch) in diameter, with various body and end types, for fresh water having a pH range from 6 to 12 and a temperature range from 0.5 to 52 C (33 to 125 F). Formerly, very large diameter butterfly valves up to 4.3 meter (168 inch) that were designed to operate under heads as great as approximately 300 meters (1,000 feet.) were designed and built only by the U.S. Bureau of Reclamation (Reclamation), but several large United States and foreign manufacturers now supply butterfly valves in even larger sizes and heads to meet the purchaser’s needs. Typically butterfly valves are provided with circular shapes to mate with conduits and penstocks; however, square and rectangular shapes are available for applications such as for water treatment plants.

3-3. Design Considerations and Limitations

a. General

Butterfly valves were designed to shut-off the flow of water in a penstock or an outlet conduit either under balanced head, no-flow conditions or in an emergency under unbalanced head, full-flow conditions. Butterfly valves have been designed to operate at heads greater than approximately 300 meters (1,000 feet). Normally, such valves are used to regulate flows only in instances where the flow velocity is low and the head differential across the valve is small.

The flow velocities through butterfly valves are usually limited between 7.6 to 9 m/s (25 to 30 feet per second), although high-performance butterfly valves can operate up to 15.2 m/s (50 feet per second). The flow past the disc in the fully open position creates eddies
and flow disturbances that can be carried to downstream valves and/or appurtenances unless proper spacing is provided downstream of a butterfly valve.

The flow-through disc design creates a greater free-flow area, thus minimizing turbulence, lowering head loss and reducing pressure drop across the valve. It has also been demonstrated that flow past biplane flow-through butterfly valve discs will stabilize in a much shorter distance downstream than conventional butterfly valves with lentil type discs. Butterfly valves can be provided with resilient seats for extremely tight shutoff capability.

b. Design Considerations

The head loss produced by a butterfly valve in a penstock feeding a powerplant may be significant when the penstock velocity exceeds 3 to 4.5 m/s (10 to 15 fps), and this has been the basis for not selecting a butterfly valve for use in such installations.

Another concern is flow turbulence as it passes the disc in installations where the valve is adjacent to a turbine or other inline piping equipment. This limitation has been overcome by carefully profiling the fluidway to increase the velocity of the water, at a constant rate or acceleration, by 1.5 m/s (5 fps) as it flows through the valve. This acceleration tends to stabilize the flow pattern before it enters the turbine.

Material selection for valve seats and seals should take into consideration flow conditions and sediment in water to avoid damage due to abrasion. Proper selection minimizes the need for future maintenance and/or costs. Manufacturers offer seal/seat designs that include metal, rubber, and polytetrafluoroethylene (PTFE) depending on design limitations. The principle advantage claimed from rubber-seated valves is that drop-tight sealing can be achieved (Kohler, 1969). Metal seals are less susceptible to damage in severe service conditions, but do not provide a drop-tight seal. The designer has to determine the relative importance of sealing efficiency and ruggedness required for each specific installation.

c. Design Limitations

Normally, butterfly valves are limited to the use described previously. Attempts to use the valves to regulate relatively high head releases, above 15 meter (50 feet) of differential head has resulted in severe consequences such that the disc suffers heavy damage from cavitation and vibration. Experience has shown that when used exclusively as a guard valve, but at very high heads, such as approximately 300 meters (1000 feet), the smallest leak past a closed disc can cause extensive damage by metal erosion, via “wire-drawing,” necessitating frequent and costly repairs.

Sealing butterfly valves is always a problem, particularly at high heads when a non-continuous seal is used, as is the case in Reclamation designed valves. It is difficult to obtain a good seal at the trunnions and around the periphery of the disc. Reclamation designs use externally adjustable seals that can be adjusted while the disc body is under operating pressure rather than the usual method that requires dewatering and adjusting the
seals from the inside. Even so, leakage of 11 to 55 l/m (3 to 15 gpm) can occur for new 4 meter (156 inch) diameter valves under 1034 kPa (150 psi) water pressure.

3-4. Operating Equipment

The operating forces on butterfly valves are usually very low with very little friction and hydraulic effects, however the dynamic flow torque is a function of the diameter cubed and for large valves will be significant. Butterfly valves are typically operated by manual or electric-motor actuators. Hydraulic actuators are also commonly used for large sized butterfly valves. Large valves may require hydraulic operation since the high-velocity flows produce dynamic torques of a magnitude that may make mechanical operation impractical [Kohler]. The operating torque varies widely depending on the angularity of the disk with respect to the centerline of the fluidway. In some cases, butterfly valves are counterweighted to close upon loss of power in an emergency condition. When a mechanical valve operator is used, the valve operator must be designed to overcome the torque when the valve is opened and resist the force while the valve is closing to prevent sudden closure. The pressure differences across the valve disk tend to force or “slam” the disk shut and could cause damage to the valve and/or transient flow concerns within the piping system. The different types of actuators are discussed in Chapter 11.

3-5. Installation and Operation Considerations

a. General

Butterfly valves are sometimes used for controlling flow, but that type of operation has to be done with caution. Rotation of the valve disc does not provide good flow control characteristics throughout the operating range, most of the flow control occurs in the mid-position of disc operation. Also, it is also difficult to introduce air into the water flow immediately downstream of the valve in order to prevent cavitation.

Most butterfly valves have flow characteristics that could slam the disc shut once closure has been initiated. Therefore, the actuator and controls must be designed to consider the possible maximum flow-induced hydraulic forces to prevent possible damage to the valve and limit potential waterhammer pulsations when making emergency closures.

Many of the butterfly valves sold in the public market are installed in penstocks (Figure 3-2) and the piping networks of water supply systems and waste water treatment plants and pumping stations. Upstream flow disturbances play a major role on the proper performance of butterfly valves and can be caused by pumps, other valves, and elbows. Flow disturbances influence the dynamic torque characteristics of butterfly valves and may reduce the total flow capacity through the valve.

The information presented in this section is intended to document installation and operation considerations when selecting butterfly valves.
b. Upstream Disturbance

The most common upstream disturbances are caused by the close proximity of butterfly valves and upstream elbows. Ideally, when locating a valve in a piping network, one should provide enough unobstructed straight piping to ensure uniform, steady flow at the entrance to a butterfly valve. This may not be feasible due to space limitations and economics. In many instances, especially penstock installations, there may be limited space for installation of butterfly valves, and the proximity to piping elbows or other in-line appurtenances may lead to a catastrophic failure of the valve as documented by Hegseth and Sehgal (1995). An example of a typical penstock installation is shown in Figure 3-3.

![Figure 3-3. Typical Penstock Butterfly Valve Installation](image)

Several butterfly valve manufacturers recommend between 6 and 8 unobstructed conduit diameters upstream of a valve. Such a distance alleviates the influences of flow disturbances on butterfly valves. When this distance is not available, incorrect valve orientations and/or unspecified disturbances can result in undersized valve actuators and potential premature valve failure. Straightening vanes can be used to reduce the amount of unobstructed upstream conduit distance.

c. Valve Shaft Orientation

If upstream disturbances are not a concern, larger butterfly valves should always be installed with the shaft axis horizontal.

If shaft orientation is vertical, the trunnion bearings of the valve can be damaged due to settling of fines and scale (and even snails) into bearing clearances. Damage might occur
prematurely due to construction debris in the conduit; or over a period of time due to settling of fines from water hardness, calcification, raw water solid content, or a variety of other sources. In all cases, the results can be detrimental to long-term performance of the valve.

One concern with orienting the valve shaft axis horizontally is hydrostatic torque. Hydrostatic torque can be a sizable operating load on large valves.

d. Disc Closure Direction

The direction of closure of the valve disc can have a major impact on long-term valve operation. Construction debris and/or system fines will settle to the bottom of the conduit and valves. Solids can accumulate and can cause damage to the valve seat and disc edge or prevent total shut-off. If the valve is installed so that the bottom disc edge creates a high local fluid velocity at the bottom edge of the seat and disc, the high velocity will sweep out sediment and debris during valve closure.

e. Disc Swing Clearance

AWWA short body butterfly valve discs protrude beyond the valve body end faces when the valve is fully opened. If this is not recognized, interference problems with mating conduit flanges or close proximity obstructions can occur. The valve manufacturer can supply the required disc swing clearance information to prevent installed disc interferences. However, the system designer should verify this clearance to prevent disc interference with the mating piping or other potential obstructions.

f. Waterhammer

This transient phenomenon can occur in systems with liquids, gases, or steam media. For dam facilities and outlet works piping systems the media is water and the phenomenon is referred to as waterhammer. The results of waterhammer can range from an irritating banging noise to catastrophic failure of valves, pumps, and/or entire piping systems. Transients can occur during initial filling of the conduit, the starting or stopping of pumps, sudden shifting of inadequately supported conduit, inadequate air removal, or valve stroking times that are too fast for the specific piping system.

Quarter-turn butterfly valves are inherently easy and fast to close, therefore, the actuator and control system must be carefully designed to limit valve closure rate.

g. Testing

Butterfly valves should be field tested in accordance with AWWA Standard C504 Rubber Seated Butterfly Valve requirements (leakage, noise, etc), industry practice, and specification requirements.
h. Materials Selection

Materials of construction should be selected in design with consideration of the water chemistry prior to valve procurement. Site specific operating conditions and limitations should always be considered when designing and installing a water control valve.

When selecting butterfly valves for potable water systems always specify material like aluminum bronze. A good rule of thumb is to at least match the disc with the piping material or slightly upgrade for added assurance. For instance, when selecting Butterfly Valves for use in iron pipe or steel systems, specify nickel plated ductile iron or aluminum bronze disc. In a copper system use aluminum bronze or stainless steel disc, and in a stainless-steel pipe system use a stainless-steel alloy.

3-6. Failure Scenarios

a. Shaft Blow-out

Certain types of butterfly valves can undergo shaft or disc separation and fail catastrophically causing severe damage to the conduit, equipment, and/or facilities. Such valve failures can occur even when the valves are operated within their design limits of pressure and temperature. A number of design and operational factors contributing to this hazard are:

Design Factors:

- The valve has a shaft or stem piece that penetrates the pressure boundary and ends inside a pressurized portion of the valve. This feature results in an unbalanced axial thrust on the shaft end which tends to force it (if unconstrained) out of the valve.
- The valve contains potential internal failure points such as shaft dowel pins, keys, or bolts where shaft disc separation can occur inside the valve disc.
- The dimensions and manufacturing tolerances of critical internal parts (for example; keys, keyways, pins, and pin holes) as-designed or as-fabricated cause these parts to carry abnormally high loads.
- The valve stem or shaft is not blow-out resistant. Non blow-out resistant design features may include two-piece valve stems that penetrate the pressure boundary, single diameter valve shafts (a shaft not having an internal diameter larger than the diameter of its packing gland) or shafts without thrust retaining devices, such as split-ring annular thrust retainers.

Operational Factors:

- The valve is subjected to high cyclic loads. If the valve slams shut with great force, repeated high stresses may cause propagation of inter-granular cracks in critical components, such as dowel pins.
• The valve is subject to low or unsteady flow conditions, such that disc flutter or chatter occur, resulting in increased wear of keys, dowel pins, or other critical internal components.

• Valves used in hydrogen rich or hydrogen sulfide containing environments may be more susceptible to blow out due to hydrogen embrittlement of critical internal components, particularly if components are made from hardened steel.

b. Cavitation

Butterfly valves can cavitate when the pressure drop across the valve disc is too large or the downstream pressure is too low. When a butterfly valve is exposed to cavitation conditions continuously, such as during modulation, significant damage can occur to the metal surfaces of the valve and/or downstream conduit in a short period of time. Therefore, modulating and throttling applications warrant an evaluation of potential cavitation conditions.

If a butterfly valve is cavitating there are several options to control or eliminate it. The primary option is to reduce the cavitation intensity by modifying the system operating conditions including reducing the flow, reducing the pressure drop or increasing the downstream pressure. Other options are to install a downstream device to increase the outlet pressure and decrease pressure drop across the valve.

c. Failure of Motor Actuated Butterfly Valves to Operate

If the friction forces exerted on the valve seat exceed the values assumed when selecting the motor actuators and setting the torque switches, the butterfly valve may fail to open on an electrical signal.

The underestimation of the friction forces that occur due to age hardening of the seat material could lead to a common failure of a large number of motor operated butterfly valves to open on an electrical signal.

d. Counterweights

Some designers/manufacturers favor butterfly valves fitted with counterweights. While the valves are opened by hydraulic cylinder actuators, the counter weights are intended to provide valve closure without power. This system permits use of single acting cylinders. But counterweight systems have had problems. Some installations have experienced conduit bursting problems due failure of counterweight holding/restriction devices allowing rapid closure of valve disc and resultant high water pressures and waterhammer surges. Historically, Reclamation seldom used counterweighted butterfly valves.
3-7. Recommendations for Improved Reliability

The following recommendations are suggested to improve the reliability of butterfly valves:

- Research to develop guidance on limiting conditions for use of butterfly valves for flow regulation. Flow characteristics and limits for butterfly valves are not generally defined in the standards/specifications nor are they defined by manufacturers in most cases [Ref. 18]. In some cases under low-head conditions, butterfly valves are used for flow regulation and documentation is needed to understand the limiting head conditions for this type of use. AWWA (2010a and 2010b) and Baran (2007) have evaluated the application of butterfly valves for free discharge, minimum pressure drop, and for choking cavitation conditions; however, this research has been limited and requires further study to develop appropriate guidelines.

- Research to improve understanding of opening butterfly valves for guard, shut-off, or emergency conditions under high-head flow conditions. In several project cases where high head conditions exist, small by-pass flow piping is used to fill the downstream piping and allow for balanced head conditions prior to opening the butterfly valve. Research may include improvement of valve seating systems.

- Research to improve guidelines for recommended upstream and downstream length of straight pipe between valve and flow discontinuity such as a pipe bend, secondary valve, etc. Further research could improve understanding of unsteady, transient flow conditions within the piping system and establish a consistent upstream and downstream pipe requirement. Currently, many projects conservatively select 10 upstream and 5 downstream pipe diameters of straight pipe to safely restore uniform flow conditions from flow through a butterfly valve and can result in an oversized vault or building.

- Materials of construction should be selected with consideration of the water chemistry.
CHAPTER 4 – FIXED-CONE VALVES

4-1. Application

A fixed-cone valve (Figure 4-1), also known as a hollow-cone or by the trademark name Howell-Bunger (copyright of Rodney Hunt Company), is commonly used for regulating flow of water from an outlet works at medium to high head dams as free discharge. A fixed-cone valve is a cylindrical valve with a longitudinally sliding sleeve that covers a cylindrical opening at the downstream end of the valve. A cone (usually 90 degrees) is installed at the end of the circular valve structure that disperses the flow radially from the opening between the valve body and the sliding sleeve (Gerbig, 2004). The expanding cone of flow and spray acts as an energy dissipater and allows for a free flow discharge as shown in Figure 4.1.

![Fixed-Cone Valve Discharge](image)

Figure 4.1. Fixed-Cone Valve Discharge (Courtesy of Dr. BTA Sagar)

Fixed-cone valves have a proven performance record and provide smooth, vibration-free operation. Fixed-cone valves, when selected and installed in accordance with the manufacturers recommendations, are cavitation free, very economical, and require less maintenance as compared to many other flow control/energy dissipation valves. Fixed-cone valve are excellent energy dissipation valves due to its highly dispersive jet (FEMA, 2010).

Fixed-cone valves were originally used to radially discharge flow freely into the atmosphere which helps to dissipate the flow energy of water. However, as the spray of the released water is often found to be objectionable especially in the vicinity of unstable sliding slopes, the proximity of electric transmission lines, etc., hoods have been added to fixed-cone valves to contain the spray. A hood can either be a separate structure (Figures 4-3 and 4-8) or attached to the valve (Figure 4-4). Containing the spray can refocus the energy of the discharge downstream and may require downstream facilities to minimize potential erosion damage. Some attempts have been made to operate fixed-cone valves submerged, but that requires careful study and evaluation.
Figure 4-2. Fixed-cone Valve (Courtesy of AVK/Glenfield Valves)

Figure 4-3. Fixed-cone Valve with Separate Steel Lined Hood (Alder Dam, WA) (Courtesy of Dr. BTA Sagar)

Figure 4-4. Fixed-cone Valve with Attached Hood (Courtesy of Lee Gerbig)
4-2. Sizes and Heads

Fixed-cone valves are available from manufacturers in sizes 0.152 to 2.845 meter (6 to 112 inch) and designed for medium to high heads up to 128 meter (420 feet) for the larger valves and up to 428 meter (1,400 feet) for the smaller valves. Fixed-cone valves are fabricated in circular shapes to mate up with circular conduits and penstocks, typically using AWWA C207 flanges (AWWA, 2013).

4-3. Design Considerations and Limitations

a. General

The construction of fixed-cone valves must be sufficiently rugged and all parts must be designed for safe and satisfactory operation at any position between fully open and fully closed without injurious vibration or cavitation. In general, working stresses should not exceed one-third of the yield strength or one-fifth of the ultimate strength of the material. The valve components will be designed in accordance with corresponding AWWA Standards. In many cases, a project may require stainless steel components for abrasion and erosion resistance to sediment laden flow conditions. The critical valve components include the following:

- **Body** – The valve body will consist of a cylinder, a steel cone with a 90-degree angle deflector on the downstream end, internal radial ribs and an upstream mounting flange for attachment to the flanged end of the outlet works pipe or penstock. The internal ribs and deflector cone are designed to extend a specified distance beyond the downstream end of the valve body cylinder to permit the rated discharge capacity and eliminate the possibility of flow control shift as noted in Section 2-5b. Guidelines for body wall and ribs sizing for valve design were presented in the report “Vane Failures of Hollow-Cone Valves” (Mercer, 1970). The body bearing surfaces in contact with the valve sleeve shall be either bronze or stainless steel to provide a stainless steel on bronze sliding control bearing surface. The mounting flange and valve components shall be designed in accordance with AWWA C207.

- **Sleeve** – The valve sleeve will consist of a cylinder designed to slide over the valve body in the upstream direction to open and the downstream direction to close the valve port. The sleeve shall seal continuously against the valve body on the upstream end and a valve body seat ring on the downstream end (ring fastened to the end of the body deflector cone edge). The sleeve bearing surfaces in contact with the valve body shall be either bronze or stainless steel to provide a stainless steel on bronze sliding control bearing surface.

- **Seals** – The valve body shall have a removable seat attached to the downstream end of the valve body deflector cone with gasket and stainless steel bolts. The sealing contact surface of the seat shall be stainless steel.

- **Hood (if specified)** – The hood will consist of a steel jet deflector hood bolted to the downstream end of the sliding valve sleeve. The hood shall operate smoothly with no cavitation and without undue vibration. The discharge end shall appear
round, cylindrical and without divergence or convergence in excess of a 10-degree total conical shape.

- **Operating System** – The valve operation shall be either a mechanical dual screw stem actuating system or dual hydraulic cylinders located diametrically opposed on the horizontal axis of the valve.
- **Coating** – Epoxy coated surface are required for velocities greater than 50 fps to 100 fps and carbon steel is suitable for flows up to 50 fps.

**b. Design Considerations**

The size of the valve is determined by the maximum available net head at the valve and dependent on the valve discharge coefficient. The desired flow rate is used to determine the size of the valve as follows:

\[
Q = A \times Cv \sqrt{2 \times g \times H}
\]

(Equation 4.1)

Where:
- \(Q\) discharge (cubic feet per second)
- \(A\) area of valve in opening based on nominal pipe cross section diameter (square feet)
- \(Cv\) dimensionless coefficient of discharge (dependent on valve opening)
- \(g\) acceleration due to gravity (32.2 ft/sec\(^2\))
- \(H\) net available hydraulic system head (feet)

The coefficient of discharge, \(Cv\), for a fully-opened fixed-cone valve is about 0.85; however, the coefficient is variable depending on valve performance design and valve opening position. With a hood attached to a fully-opened fixed-cone valve, the coefficient is reduced to between 0.70 to 0.79, depending on the manufacturer. Typically a range of valve discharge coefficients is developed through shop testing experimentation and a supporting rating curve is prepared. The discharge coefficients are developed by measuring the effectiveness of energy dissipation at different percent valve openings. The area of valve opening between the sleeve and body seats is not a direct input into the fixed-cone valve discharge equation, instead dependent factor on the development of the range of discharge coefficients. Several design issues have been identified associated with the amount of allowed valve open area, the design of the valve internal structural members, and design of the dissipation hood. These concerns are further discussed in Section 4-3.

**c. Design Limitations**

Historically, the hollow-cone (fixed-cone) valve design was developed through improvements that have been made as a result of documented failures and performance testing. Laboratory and/or prototype testing was conducted to improve valve hydraulic performance, established valve sizes and preferred materials, limit vibration and cavitation issues, and model site-specific flow conditions to support project design.
The overall design of fixed-cone valves has improved through a better understanding of hydraulic limitations on specific mechanical valve components. The following is a discussion regarding design implications for internal valve cone vanes and valve hood concepts:

**Vane Failures of Fixed-Cone Valves**

The fixed-cone valve is intended for controlled release of water at the downstream end of a pressure conduit; however, in some cases improper designs have led to failures as a result of excessive vibrations within the line. Vibrations can arise from improper outlet works designs through irregular upstream flow passages, inadequate ventilation downstream of the valve, or faulty product manufacturing. In some reported cases the failures resulted from the valves themselves creating the vibration failure; especially, for very large discharges. The cases were characterized by the cracking and bending of the interior stay-vanes that support the valve cone and were studied by Dr. Albert G. Mercer with the Colorado State University. The case study was documented in *Vane Failures of Hollow-Cone Valves* (Mercer, 1970). The study developed a parameter based on hydroelastic principals that could establish if the failure was because of improper stay-vane considerations and that there is a corresponding critical discharge in which causes destructive resonances. Vane failures of hollow-cone valves were closely associated with a kinematic condition of flow related to vibration frequencies of the vane. The parameter is recommended for use as a criterion for determining vane thickness in future valves or discharge limits for existing valves.

**Hood or Baffle Design for Fixed-Cone Valves**

Fixed-cone valves are designed to emit a large-diameter conical spray; which is effective at spreading and dissipating energy. Although, in some conditions where space is limited the structure design may require containing the spray; which is typically achieved using a hood. As previously discussed, fixed-cone valves discharging through a hood do not dissipate the energy of the jet as well as a fixed-cone valve without hood. Fixed-cone valves with hoods result in a high velocity hollow jet that focuses the energy directly downstream; which in many cases requires energy dissipation basins, stilling pools or similar structures that may be needed to avoid severe erosion of the river bed and other related problems. However, in some cases these types of energy dissipation works are invariably found to be expensive and often unsatisfactory in their performance. Other design concepts have been studied to dissipate some of the energy of the concentrated jet prior to impingement in the stilling basin. Documentation is provided below regarding the improvement of the fixed-cone valve hood design.

Other applications using fixed-cone valves for energy dissipation have been installed without complete success preventing downstream erosion. These applications use the principles of impinging-jets and downstream baffle structures to provide energy dissipation as shown in Figure 4-6 and Figure 4-7 (Falvey,
The ring deflector was damaged during operation of the energy dissipator because of a weld failure on the steel cladding (Devries, 1994). Subsequent inspection found that a large void had been left in the concrete behind the steel liner when it was placed. Figure 4-6 is a profile schematic view of a fixed-cone valve installation with deflector ring at the Oroville Dam Outlet Works in California (Falvey, 2004). A new deflector ring which was 85-percent of the original ring height was successfully commissioned in the summer of 2016. The original design and new design both effectively dissipate the massive energy associated with a high head flow installation at Oroville Dam, which operates under about 750 feet of hydraulic head. The hydraulic design was modeled by Utah State University and California DWR should be contracted for further details.

Various modifications of this design concept have been developed including hoods on fixed-cone valves that discharge into the atmosphere as shown in Figure 4-7. The distance between the end of the fixed-cone valve and the hood is critical. Severe blowback/backsplash has been experienced in prototype installations where this distance was off by only an inch or two.
As discussed above, backsplash can be a problem for fixed-cone valves installed with a separate hood. The U.S. Army Corps of Engineers research lab at the Waterways Experiment Station (WES) investigated possible solutions to control back splash (Maynord, 1981 and Fagerburg, 1983) for the 78-inch fixed-cone valves installed at New Melones Dam (Figure 4-8). The fixed-cone valves discharge through a 15.5 feet (4.72 meter) long by 15.5 feet (4.72 meter) diameter hood not attached to the valve. One solution was to revise the location of the back splash plate attached to the inside of the hood.

![Figure 4-8. 78-Inch Fixed-cone Valve with Separate Hood (New Melones Dam. Sketch and Photo Courtesy of WES)](image)

Recently, a baffled hood (not attached to the valve) was developed (Figure 4-9) that is capable of dissipating over 92% of the energy (power) available upstream of the fixed-cone valve (Johnson, 2006 and Johnson, 2001). The focus of the study was to present practicing engineers with information to help assess alternative means of dissipating energy when utilizing fixed-cone valves to regulate and control discharge where space to discharge the hollow jet is limited. A concern with the introduction of baffles in the hood is whether the baffles reduce the discharge capacity of the valve and limit air typically drawn into the hood. However, the study results demonstrated that there were no changes in hood air demand or reduced discharge capacity. Back-splash is a concern with hooded fixed-cone valves and can be reduced or eliminated with proper hood design and placement. A baffled hood design at a Peru site met the energy dissipation and back splash requirements of the installation and performed exceptionally well. Figure 4-10 demonstrates the dampening effect of the non-attached hood with baffles on the jet flow for a fully opened fixed-cone valve. The referenced study utilized a ratio of hood diameter to the valve diameter of approximately 3:1. Additional studies have been completed which demonstrate that baffles may be added to conventional hoods and effectively dissipate energy in free discharge and submerged conditions. While the research conducted provides excellent guidelines for baffled hood installations, engineers should consider modeling for design verification or design review by one experienced with such installations (Prettyman, 2015; Prettyman, 2014; and Stephens, 2012).
With additional research and development, there is a good possibility that the attached hood (Figure 4-4) could incorporate similar baffles and perform properly. With proper design based upon hydraulic model studies, fixed-cone valves should be able to perform as energy dissipating valves with minimal or no vibration.
4-4. Operating Equipment

The fixed-cone valve sleeve may be actuated by a twin-screw mechanism, a linkage mechanism, or twin hydraulic cylinders. The actuator may be a hand wheel, an electric-motor, or a hydraulic-motor. The actuators are typically mounted on top of the fixed-cone valve.

The fixed-cone valve sleeve is commonly controlled by twin screws one at either side of the valve. The twin screws are driven by dual drive shafts and a gear box located above the fixed-cone valve (Figures 4-1, 4-2 and 4-3). The gear box transmits torque to the drive shafts, which turn the twin screws and slide the valve sleeve forward (downstream) to decrease or shut-off flow, or backwards (upstream) to increase flow or fully-open valve. In any opened position, flow is dispersed radially through the opening between the sleeve and the cone-shaped deflector head on the valve body.

Alternately, the linkage mechanism or twin hydraulic cylinders can be used instead of a twin screw to move the valve sleeve. A linkage mechanism would be operated by a hand wheel or motor actuator. Twin hydraulic cylinders would be operated by pressurized oil from a hydraulic power unit.

4-5. Installation and Operation Considerations

In addition to the WES research described in Section 4-3, research was performed at WES to determine the operational effect a higher pool elevation would have on the 78-inch fixed-cone valves installed at New Melones Dam outlet works (Fagerburg, 1983). The purpose of the tests was to determine (at higher pool elevation) the dynamic response of the valves, and probability of valve-fatigue type failure at prolonged operation. Test results include information on discharge characteristics of the fixed-cone valve, evaluations of pressure fluctuations in the valve and hood, vibration of the valve and hood, and strain measurements of a valve test vane. Data revealed no significant changes due to increase in pool elevation. Research results determined that the mean pressure values in the valve and hood increased due to increase in total head, and no negative pressures were recorded. Flow control shift occurs in most fixed-cone valves since at small openings the flow is controlled along the sleeve lip and at large openings a point is reached where the control shifts to the downstream edge of the fixed shell. The occurrence of flow control shift was prevented for the New Melones Dam experiment by limiting the total sleeve travel (to a maximum of 28.1 inches). See paragraph 2-5b for a discussion on flow control shift.

The following considerations are applicable to fixed-cone valve installation and operation:

- Flow can be controlled very well at all but the smallest valve openings.
- The fixed-cone valve must be the primary flow control valve and all upstream valve(s) should be in the fully opened position (not throttling flow). This will ensure
steady uniform flow conditions, avoiding fluctuating flow that could lead to possible vibration damages to the fixed-cone valve.

- Fixed-cone-valves are not suitable for use in submerged applications unless supported by appropriate hydraulic model studies. Example projects with submerged fixed-cone valves provided by Dr. Michael Johnson of Utah State include New Castle Dam and Logan City Hydro #2.
- Some manufacturers state that fixed-cone valves with attached hoods are not suitable for heads above 53 meter (175 feet); however, model testing on ring-jet valves at Utah State have observed no performance problems up to 137 meter (450 feet) of head.

There are no detailed installation and operations considerations provided in this document, but the general installation and operational considerations would be followed and shop and field testing of each fixed-cone valve should be in accordance with industry practices and specification requirements.

AWWA Standards require shop testing for fully assembled valves shall include hydrostatically, leakage, and operational testing. The hydrostatic test will be conducted for 30 minutes at a pressure of 1.5 times the rated valve pressure. There shall not be any evidence of leakage. The leakage test will be conducted for 5 minutes at the rated pressure will allowable leakage through the downstream metal seats to not exceed 5.0 ounces per minute per inch of valve diameter (for valves with rubber insert seals there shall be no evidence of leakage). Valve operation testing will include fully opening and closing the valve three times using actuating mechanisms to demonstrate smooth free operation.

Materials of construction should be selected in design with consideration of the water chemistry prior to valve procurement. Site specific operating conditions and limitations should always be considered when designing and installing a water control valve.

4-6. Failure Mechanisms

Some failure mechanisms that have occurred with fixed-cone valves are:

- Vane failures have occurred on a number of fixed-cone valves. At one location, after initial failure, much thicker vanes were installed. In a short time of operation, the thicker vanes also failed. The reason for both failures was a shift in control point
- Devices to control the jet, such as hoods, are also prone to damage from vibration if not properly designed. To control the vibration the mass of the guide is often increased by casting a concrete sleeve around the guide. This has a higher cost associated with this measure.
- The internal ribs, sometimes called splitters, in the bodies of the larger valves have been known to crack due to fatigue due to flow-induced vibrations. This problem has been corrected in later designs by increasing the thickness of the ribs (Mercer, 1970).
4-7. Recommendations for Improved Reliability

The following recommendations are suggested to improve the reliability of fixed-cone valves:

- Research should be conducted to develop guidance for variation of air demand for fixed-cone valves.
- Research should be conducted to develop a baffled hood that is attached to the valve.
- Research to improve inline flow control and energy dissipation within the confinement of the conduit should be conducted.
- Materials of construction should be selected with consideration of the water chemistry.
CHAPTER 5 - SLEEVE VALVES

5-1. Application

a. General

A sleeve valve dissipates energy and controls flow by diverting flow through multiple orifices or nozzles located within the valve sleeve, discharging to surrounding atmosphere or to a body of water. Sleeve valves are typically used for turbine bypass discharge, reservoir discharge, groundwater discharge, and water treatment plant flow control.

The more popular styles of sleeve valve (Figure 5-1) are the downflow submerged discharge, inline, Y-pattern, and angle pattern. A modified version of the downflow submerged discharge style is a multiport sleeve valve with larger ports to minimize clogging. The valve controls flow by sliding an outer conduit called the gate over the inner conduit called the sleeve. The sleeve is designed with multiple sized and spaced tapered orifices or nozzles. As flow passes through the nozzles in the sleeve, energy is dissipated during a mixing process in an inner chamber of the valve.

Much of the information contained in this chapter is based on information provided in Bailey Valve Corp literature and Lindsey Fabrication documentation (Lindsey).

![Figure 5-1. Types of Sleeve Valves (Courtesy of Bailey Valve Inc.)](image-url)
b. Advantages

Sleeve valves have the following advantages:

- Sleeve valves can operate with high differential pressure across the valve.
- Sleeve valves can be designed to operate free of damaging cavitation and vibration for prolonged periods. This is accomplished by nozzle action through the sleeve component, which balances the fluid forces within the valve and the water jets strike each other instead of the valve walls to prevent damage.
- Sleeve valves do not require air demand to control or suppress cavitation.
- Sleeve valves can normally replace several standard valves in series or parallel.
- Sleeve valves can control flow or pressure over entire sleeve stroke, from fully closed to fully open.

c. Disadvantages

Sleeve valves have the following disadvantages:

- typically, more expensive than other types of control valves;
- function as strainers and will collect debris and clog; and
- more rigorous design to ensure precise flow control.

5-2. Sizes and Heads

Sleeve valves, depending on the valve model and manufacturer, can range in size from 0.076 to 1.830 meter (3 inch to 72 inch) with pressure class rating up to 7 mPa (1000 PSI). Also depending on the model and manufacturer, the sleeve valve is capable of flowing from 75 l/s (20 gpm) to over 28 kl/s (440,000 gpm.)

5-3. Design Considerations and Limitations

a. Valve Sizing

Once the valve configuration (submerged, inline, Y-Pattern, or angle) has been selected, the next step is to size the valve for the operating conditions. This is first done by collecting the following data, which will be used to determine the severity of cavitation as indicated by the cavitation index ($\sigma$), flow velocity, and flow capacities. The sigma value (or cavitation index) is calculated and used to determine the performance class of sleeve valve, or to determine if alternate options such as ball valves or butterfly valves are acceptable for the application conditions.
Bailey Valve Inc. literature provides detailed information on the following parameters relevant for sizing a sleeve valve:

- Maximum Flow Rate
- Inlet Pressure at $Q_{\text{max}}$
- Outlet Pressure at $Q_{\text{max}}$
- Minimum Flow Rate = $Q_{\text{min}}$
- Inlet Pressure at $Q_{\text{min}}$
- Outlet Pressure at $Q_{\text{min}}$

**b. Backpressure Requirements**

Although sleeve valves will withstand a much higher differential pressure than other control valves, some designs still require a back pressure on the exiting flow from the valve. The downflow submerged discharge type sleeve valves (Figure 5-1) by their nature, typically have a back pressure of approximately 4 meter (13 feet) on the exiting flow from the nozzles (Watson, 1977 and Clinton, 1973). Inline, Y-pattern, and angle pattern sleeve valves, like other types of control valves, usually indicate their backpressure requirements through the allowable cavitation index defined as:

\[
\sigma = \frac{(P_o - P_v)}{(P_i - P_o)} \quad \text{Equation 5.1}
\]

Solving for the minimum outlet pressure:

\[
P_o \geq \frac{(P_i \sigma + P_v)}{(1 + \sigma)} \quad \text{Equation 5.2}
\]

Where:

- $P_o$ Outlet pressure
- $P_i$ Inlet pressure
- $\sigma$ Cavitation index
- $P_v$ Vapor pressure

**c. Minimum Submergence**

For submerged discharge, the designer or specifier should consult with the valve’s manufacturer to determine the minimum required submergence.

**5-4. Operating Equipment**

Sleeve valves can be configured for operation by manual screw, motorized, or hydraulic actuators. Manual screw type actuators in a control stand are suitable for operating valves up to about 0.60 meter (24 inch) diameter, but a motorized actuator or a small hydraulic cylinder actuator with an electric motor driven oil pump are required for larger valves.
5-5. Installation and Operation Considerations

a. General

Materials of construction should be selected in design with consideration of the water chemistry prior to valve procurement. Site specific operating conditions and limitations should always be considered when designing and installing a water control valve.

b. Debris Removal

Debris collection is an inherent problem for all sleeve valves. The downflow submerged discharge sleeve valve requires the sump to be drained before the debris can be removed. The inline, Y-pattern, and angle pattern sleeve valves should have large access ports and cleanouts. The size of the cleanouts depends on the size of the valves, but larger is better for access. Access ports from 0.2 meter (8 inch) to 0.6 meter (24 inch) are recommended (Figure 5-2). For larger valves, it is recommended that access is to the downstream side of the valve to enable debris jammed into the tapered nozzles to be forced out.

![Figure 5-2. Eight-inch Cleanout in a ten-inch diameter valve in a Ten Inch Valve. (Courtesy of Bailey Valve Inc.)](image)

c. Isolation Valves

Depending on the installation, it is recommended that isolation valves be placed both upstream and downstream of the sleeve valve. If butterfly valves are used as isolation valves, it is recommended that the maximum velocity in the conduit should be less than 5 m/s (16 ft/sec). If the conduit velocity is 5 m/s (16 ft/sec) or higher then consideration should be given to using special high velocity butterfly, ball, conical plug, or gate valves, or knife-gate valves as isolation valves. If butterfly valves are used for isolation downstream, it should be no closer than four to six conduit diameters from the sleeve valve. Knife-gate valves can be located closer to the sleeve valves (than butterfly valves), because there is very little disturbance in the flow when the knife-gate valve is fully open. The relative position of the ball or gate isolation valves is not critical. If the outlet flow from the sleeve valve passes through a 45° or 90° bend or if the exiting fluid
is rotating about the axis of the conduit due to nozzle geometry, then ball or gate type isolation valves should be considered instead of butterfly valves.

d. Noise

The noise associated with inline, Y-pattern, and angle pattern sleeve valves is generally a function of the total energy conversion and dissipation in the valve and the velocity of approach to the nozzles in the sleeve and in the body downstream of the sleeve. The level of acceptable noise will depend on the site-specific installation requirements. Residential areas will require less noise than remote locations. The following factors are generally considered the major causes of sleeve valve noise.

Body and Sleeve Velocity – Maximum sleeve velocities in the range of 6-7.5 m/s (20–25) ft/sec will generally result in quiet running valves suitable for residential areas. Sleeve velocities in the range of 11-12 m/s (35-40 ft/sec) are typically acceptable for temporary turbine bypass situations, usually in remote locations.

Pressure Drop - The noise associated with sleeve valves generally is directly related to the logarithm of the head loss across the valve. The actual noise level will depend on the design of the sleeve valve. Test data indicates that approximately a 10 dBA increase in noise can be expected for each ten-fold increase in differential head across the valve (Tullis, 1987 and Tullis, 1989b).

Mechanical Vibration – Major sources of noise associated with mechanical vibration are:

- clogged nozzles in the sleeve causing a non-uniform flow pattern inside the valve;
- unequal velocity head or pressure acting on the sleeve and nozzle area;
- obstructions in the flow path, such as internal ribbing and supports that cause cavitation bubbles to collapse on metal parts of the valve;
- premature release of core cavitation into an area of rapid expansion; and
- isolation valve not dynamically stable in the open position.

Cavitation – Properly designed sleeve valves will not produce a situation where cavitation bubbles will collapse on the valve or downstream piping. If the cavitation bubbles are surrounded by water when they collapse, then the high frequency noise normally associated with high velocity cavitation bubble collapse on metal is eliminated.

e. Testing

There are no detailed testing instructions provided in this document, but the installer should follow shop and field testing of each sleeve valve in accordance with industry practices and specification requirements.
5-6. Failure Mechanisms

Design of sleeve valves is very complicated compared to other types of valves, but the ability of these valves to distribute high differential pressure across the valve and operate free of damaging cavitation and vibration for prolonged periods are benefits that other valves cannot provide. The complicated design of these valves also leads to major failure mechanisms as further described below. Include improper design leading to excessive vibration or cavitation or related to sleeve valves include improper design.

The proper application of a sleeve valve starts with a basic understanding of the important design parameters that affect the performance of sleeve valves such as noise and vibration, back pressure requirements, debris removal and proper sizing consideration. A key factor in the proper sizing of any multijet-sleeve valve is to know the maximum flow through the valve with consideration of the minimum differential head across the valve (Lindsey and Hartman). These considerations are important because they could have an impact on the service life of a sleeve valve. Improper design can lead to excessive vibration and cavitation conditions that cause failure of a mechanical valve component.

The multi-jet type of sleeve valve is particularly well suited for throttling high head releases, above 45 meter (150 feet), but the ports are susceptible to plugging by debris. Therefore, high head throttling usage is best limited to installations where there is little likelihood of debris in the water.

5-7. Recommendations for Improved Reliability

Proper material selection, especially the material selected for the seals and seat ring and proper application of the sleeve valve should provide a reliable installation. For downflow submerged discharge, the bottom of the stilling well should be lined with steel and have deflector plates to protect it from cavitation and abrasive damage unless the well is oversized.

Successful application of sleeve valves requires an understanding of the importance of noise, vibration, back pressure requirements, debris removal, and proper sizing to handle the maximum flow with minimum differential pressure across the valve.
CHAPTER 6 – SPHERICAL VALVES

6-1. Application

Spherical valves (Figure 6-1) are used in high velocity applications. The valves are used exclusively as guard or emergency valves in high head outlet works (and not for regulation). Power plants are ideally suited for installations where the turbine and the guard valve are very close together and are designed and built by commercial valve manufacturers. The spherical valve is intended to act as a guard or emergency valve and to be operated in the fully open or the fully closed positions only. The spherical valve, as the name implies, is roughly spherical in shape, and contains an internal movable sphere or part of a sphere that rotates 90 degrees between the open and closed positions of the valve. The valve has an unobstructed circular fluidway completely through the open valve, but when the internal member is rotated 90 degrees, the fluidway is blocked. Spherical valves provide a full diameter unobstructed opening and, as a result, have minimal head loss in the fully open position. Spherical valves are intended to be opened with balanced conduit pressure upstream and downstream of the valve sphere. Spherical valves are capable of providing emergency closure under full flow.

6-2. Sizes and Heads

Spherical valves have been manufactured in sizes up to approximately 3.0 meter (10 feet) in diameter and heads over 600 meter (2,000 feet). Higher head applications tend to be smaller size.

6-3 Design Considerations and Limitations

Spherical valves are provided with both upstream and downstream seals. The downstream seal is used for normal operation and is actuated by water pressure from the conduit. The upstream seal is a maintenance seal that is manually set using jacking bolts. Spherical valves are supplied with both upstream and downstream extensions for installation. The upstream extension is welded to the conduit. The downstream extension is installed with an expansion coupling to ease installation and to ensure that a longitudinal load is not transmitted to a turbine spiral/distributor case or to an outlet conduit.

Spherical valves are supplied with a bypass system to equalize pressure across the valve sphere or rotor permitting opening under balanced head conditions. The bypass system is typically a needle type valve and is provided with shut-off valves on both upstream and downstream sides. The conduit should be supplied with thrust collars upstream of the spherical valve so that no horizontal load is transmitted to the valve foundation.

Spherical valves are constructed with the rotor shaft orientated horizontally for installation of the operating lever and connection to the operating cylinder(s). Spherical valves have been supplied with single or dual operating cylinders. The valve operating
lever is typically supplied with a counterweight to permit emergency closure under full flow conditions.

Spherical valve bodies are typically multi-piece construction for installation of the valve rotor or sphere and the upstream and downstream seals. The location of the main body connection flange varies somewhat between manufacturers and may be either on the valve rotor centerline or just downstream of the rotor centerline.

6-4. Operating Equipment

Spherical valves are typically operated using one or two hydraulic cylinders. Hydraulic pressure has been supplied using either water pressure from the conduit or from an independent hydraulic power unit. The bypass system operation is also integrated into the hydraulic system.

Water based hydraulic systems tend to be more maintenance intensive due to corrosion problems over time. As a result, an oil based hydraulic system using a freestanding hydraulic power unit is preferred. The hydraulic system should be provided with sufficient pressure storage at minimum operating pressure to be capable of closing the valve in the event of power failure.

6-5. Installation and Operation Considerations

Spherical valves should only be used in the fully-open or fully-closed position and are not recommended for throttling applications. Spherical valves should be opened only under balanced head conditions. Opening the valve without a fully balanced head risks damage to the valve seal. The main disadvantages to the valve are its high initial cost and the fact that it is a large valve requiring more space to install than a butterfly valve. Once the valve is installed, a significant problem is keeping the valve seals and interior cavities free of debris, silt, and mineral deposits.

There are no detailed installation and operations considerations provided in this document, but the general installation and operational considerations would be followed and shop and field testing of each spherical valve should be in accordance with industry practices and specification requirements.

Materials of construction should be selected in design with consideration of the water chemistry prior to valve procurement. Site specific operating conditions and limitations should always be considered when designing and installing a water control valve.

6-6. Failure Mechanisms

Operational problems with the spherical valve operating seal can occur if the seal water is not clean and dirt/silt enters the small water passages that are used for seal actuation and retraction. Corrosion of the valve seal and/or valve body can prevent proper seal operation.
Where a spherical valve is used as the inlet valve on a Francis type turbine, the bypass system may not be able to achieve complete pressure balance across the spherical valve to permit opening under balanced head conditions if the turbine wicket gate leakage exceeds the bypass valve capacity.

6-7. Recommendation for Improved Reliability

Materials of construction should be selected with consideration of the water chemistry. The seal water operating bypass system should have filters/strainers that are properly selected and maintained to remove dirt from the water and allow only clean water to enter the valve seal areas. Differential pressure gages-switches can be used across the filters/strainers to monitor equipment condition and to indicate when maintenance is required. The valve bypass system should be monitored to confirm proper operation and pressure balance across the spherical valve prior to opening the spherical valve based on differential pressure measurement.

![Typical Spherical Valve Construction](image)

Figure 6-1. Typical Spherical Valve Construction. Type A is a full sphere arrangement. Type B is a partial sphere arrangement.
(Courtesy of Dr. BTA Sagar)
CHAPTER 7 - CONICAL PLUG VALVES

7-1. Application

Conical plug valves (Figure 7-1) can be used for a range of flow and pressure control applications including: pump discharge and check valve service, pressure regulating valve, isolation valve, emergency closure, and level regulating service. Also, they are suitable for use in sewage applications. Conical plug valves can be used where velocities exceed 4.5 m/s (15 ft/s). The valves have a straight through unobstructed fluidway when fully opened and an internal (cylinder or truncated cone) plug that rotates 90 degrees to effect closure. For dam applications and purposes of this report, the conical plug valve use is limited to guard or shut-off service.

7-2. Sizes and Heads

Conical plug valves have been manufactured in sizes up to approximately 2.1 meter (7.0 feet) in diameter and heads over 480 meter (1,600 feet).

7-3. Design Considerations and Limitations

The conical plug valve provides an unobstructed full diameter opening in the fully open position, and as a result, has minimal head loss. The major valve components consist of a body, stem, plug, cover, and the operating equipment. The valve plug is shaped as a conical element. The valve is constructed with the shaft perpendicular to the waterway and can be used with the shaft in the vertical or horizontal position. It is preferred to have the shaft in the horizontal position for larger size valves, since it allows better access to the actuator for maintenance. The plug can be supplied with either single or dual seats. Dual seats are used to protect the valve body in the open position. Seats are typically welded on the plug.

7-4. Operating Equipment

When operating the valve in a non-throttling application from the fully closed or open position, the actuator must first lift the plug, rotate it 90 degrees, and then re-seat the plug. Conical plug valves have been provided with pneumatic, electric, hydraulic, or manual actuators. Manual operation is typically limited to smaller sizes. Hydraulic pressure has been supplied using either water pressure or from an independent hydraulic power unit.

Water based hydraulic systems tend to be more maintenance intensive due to corrosion problems over time. As a result, an oil based hydraulic system is preferred over the water-based system. Oil based hydraulic operating systems are available using a conventional free standing hydraulic power unit or a self-contained hydraulic power unit.

Where emergency closure is required, the operating system should be provided with sufficient pressure storage at minimum operating pressure to be capable of closing the
valve in the event of power failure. Where throttling is required, the actuator must be capable of re-seating the valve plug in an intermediate position for valve stability.

7-5. Installation and Operation Considerations

Although used in a wide range of applications, their availability in larger sizes and high-pressure ratings pose limitations on their application.

There are no detailed installation and operations considerations provided in this document, but the general installation and operational considerations would be followed and shop and field testing of each conical plug valve should be in accordance with industry practices and specification requirements.

Materials of construction should be selected in design with consideration of the water chemistry prior to valve procurement. Site specific operating conditions and limitations should always be considered when designing and installing a water control valve.

7-6. Failure Mechanisms

Conical plug valves have provided many years of reliable service. An area of concern is the valve seat(s). It should be verified during shop testing that seat leakage is uniform along the plug to body seat engagement. Any concentrated leakage should be corrected and re-tested. Concentrated leakage will result in rapid seat wear due to wire drawing.

7-7. Recommendations for Improved Reliability

The following recommendations are suggested to improve the reliability of conical plug valves:

- Materials of construction should be selected with consideration of the water chemistry.
- Use a free standing hydraulic power unit where oil-based hydraulic systems are used, to improve maintenance access.

Figure 7-1. Conical Plug Valve (Courtesy of Rodney Hunt Company)
CHAPTER 8 – PLUNGER VALVES\(^1\)

8-1. Application

The plunger valve (Figure 8-1) evolved from needle and tube valves. The plunger valve was developed by VAG Valve, Ltd. for flow control and energy dissipation for facilities such as transmission conduit, dam outlet works, and hydropower. Information provided by VAG states that the valve forms a relatively symmetrical flow pattern (Figure 8-2) which reduces vortex formation and potential vibration, which is especially important for a valve required to operate at less than 30 percent open for extended periods. This was accomplished by streamlining the flow passages and optimizing pressure gradients as water flows through the valve.

![Figure 8-1. Typical Plunger Valve](image1)
![Figure 8-2. Flow Pattern](image2) (Courtesy of VAG Valve, Ltd.)

8-2. Sizes and Heads

The plunger valve is available in sizes ranging from 0.1524 meter to 1.626 meter (6 inch to 64 inch) with an operating pressure up to 10 mPa (1450 psi), and is available in three classes of ANSI 150, 300, and 600.

8-3. Design Considerations and Limitations

Plunger valves are available in three standard outlet configurations and can be provided custom designed outlet configurations. Figure 8-3 illustrates a standard seated ring for flow control, a slotted and an orifice cylinder for energy dissipation, a custom designed outlet which combines slots and seated ring or orifice and seated ring, and a double or triple-layered orifice cylinder used for extremely high head applications. The manufacturer does not recommend the orifice outlet when debris or suspended particles are present or are expected in the flow stream. For this condition, the slotted outlet, or a combination of slotted and seat ring outlet is recommended. This will allow the debris to pass. The valve manufacturer should be consulted when determining the outlet configuration.

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\(^1\) This chapter is based on information provided by VAG Valves Ltd.
The plunger body seats against grooved rubber seals at the upstream end and has an ethylene propylene diene monomer (EPDM) rubber profile sealing ring that seats against a stainless steel seat at the downstream valve body end. The valve manufacturer states based on the performance of worldwide installations in last twenty years, that the plunger valve alleviates flow-induced vibration, reduces noise to an acceptable level, and eliminates cavitation damage or limits it to an acceptable level.

![Figure 8-3 Plunger Valve Outlet Configurations (Courtesy of VAG Valve Ltd.)](image)

### 8-4. Operating Equipment

The plunger valve is capable of being operated by pneumatic or hydraulic cylinders, electric motor, or manual gear actuators. The plunger valve requires low input operating torque, similar to gate or sleeve valves, to operate, primarily due to the pressure-balanced design of the moving cylinder.

### 8-5. Installation and Operation Considerations

The plunger valve can be installed inline as a flow control or energy dissipation device at the end of a conduit for free discharge. Figure 8-4a illustrates a free discharge installation with no hood or conduit attached to the outlet flange of the valve. The water level in the stilling basin is below the valve. Figure 8-4b shows a valve installed in a discharge chamber for free discharge with a hood attached to the end of the valve. The water level in the stilling basin is below the valve.
Figure 8-5 shows a schematic drawing of a 0.9 meter (36 inch) plunger valve installed at Lake Dorothy Tunnel Outlet in Alaska. It was installed in a discharge chamber for free discharge with an enlarged conduit attached to the discharge flange of the valve. In this application, a venting conduit was also added to further lessen the potential for cavitation.
There are no detailed installation and operations considerations provided in this
document, but the general installation and operational considerations would be followed
and shop and field testing of each plunger valve should be in accordance with industry
practices and specification requirements.

Materials of construction should be selected in design with consideration of the water
chemistry prior to valve procurement. Site specific operating conditions and limitations
should always be considered when designing and installing a water control valve.

8-6. Failure Mechanisms

The orifice outlet can trap oversized debris inside the valve requiring increased
maintenance. It is important that the specifier consider the quality and cleanliness of the
water passing through the valve and consult with VAG to determine the best outlet
configuration that will minimize potential debris impact on maintenance requirements.

8-7. Recommendations for Improved Reliability

As evolved from the needle and tube valves, the plunger valve has been improved and
optimized to the point where the valve itself becomes reliable for high head applications,
as claimed by VAG, based on the performance of more than 4000 installations. From a
system-wide point of view, it would be optimal to provide relatively uniform approach
flow upstream of a plunger valve which requires a straight conduit section with a length
at least twice the conduit diameter. For inline installations, providing a straight conduit
section downstream of a plunger valve with a length three times the conduit diameter
ensures that little cavitation damage would occur to the downstream conduit.

The following additional commendations are suggested to improve the reliability of
plunger valves:

- Materials of construction should be selected with consideration of the water
  chemistry.
- Use a free standing hydraulic power unit where oil-based hydraulic systems are used,
  to improve maintenance access.
CHAPTER 9 – JET-FLOW GATE VALVES

9-1. Application

Jet-flow gate valves are commonly used on outlet works as regulating valves. They have been in use by the U.S. Bureau of Reclamation since the late 1940s. Several manufacturers have adopted the design and made them commercially available. Jet-flow gate valves are usually installed at the downstream end of outlet works conduits for free discharge service, although a few have been installed below tailwater elevation for submerged discharge. A jet-flow gate valve is a bonneted slide gate with round tapered orifice for contacting the flow and assisting with the introduction of air to eliminate cavitation. A moving disc slides over the orifice to control the opening and the flow of water. Most jet-flow gate valves are installed with the fluidway horizontal, but several have been installed with the fluidway tilted downward approximately 30 degrees, to provide a deeper plunge into the stilling basin or pool. The discharge jet is fairly well contained with low loss of energy.

Jet-flow gate valves have historically been slightly more expensive than fixed-cone valves, but maintenance records over the past 50 years indicate that jet-flow gate valves are very trouble-free. Jet-flow gate valves can operate over a very wide range of openings, with no vibration or cavitation issues, even down to minute openings. A short, enlarged discharge conduit is usually attached to contain and direct the flow. At small gate openings, the flow tends to pitch downward against the discharge conduit, and then at greater openings (30 to 40 percent open) the flow straightens out and forms a naturally confined jet not touching the discharge conduit. The enlarged discharge conduit allows air to flow backward into the downstream side of the orifice area to eliminate cavitation. If the discharge conduit is longer than 1 to 1.5 times the diameter, vents are provided for air entrainment. Jet-flow gate valves can be operated manually (for smaller sizes), or by electric or hydraulic actuators.

9-2. Size and Heads

Jet-flow gate valves have been manufactured from 0.150 mm to 2.3 meter (6 inch to 90 inch) in diameter, depending on the flow requirements, and with operating heads as high as 193 meter (635 feet). Although most jet-flow gate valves use a sliding disc, several larger jet-flow gate valves, 1.7 meter (68-inch) to 2.3 meter (90-inch) for very high heads, use wheels on the disc to reduce friction loads and actuator size. The coefficient of discharge from a fully-opened jet-flow gate valve is approximately 0.84, similar to fixed-cone valve discharge coefficients.

9-3. Design Considerations and Limitations

a. General

Jet-flow gate valves are designed as free discharge, regulating gates for outlet works, and for powerplant bypass systems. Due to the inherent design and flow characteristics, jet-
flow gate valves can operate cavitation free at all gate openings and all free discharge conditions. There are several installations with jet-flow gate valves installed for submerged discharge, which requires a large diameter, but short length discharge conduit with additional air vents. A 42-inch (1.067 meter) jet-flow gate valve and discharge conduit is illustrated in Figure 9-1.

![Figure 9-1. Forty-two Inch Hilton Jet-Flow Gate Valve and Discharge Conduit (Courtesy of Hilton Valve Inc. now DeZURIK)](image)

**b. Design Considerations**

Jet-flow gate valves rely on a metal-to-metal seal between the seal ring and the sliding disc; which provides very tight shutoff with proper machining but they are not drop-tight. The seal ring is usually made with a 45 degree taper on the upstream side, which diverges to the orifice diameter. The seal ring floats in position, so that it can maintain contact with the disc at all gate openings, and has enough flexibility to follow the deflected contour of the disc due to the water load. The seal ring is set in the body with an O-ring to prevent leakage and is held in place by a seal ring clamp. The clamp and seal ring can be easily removed for maintenance.

In order to provide cavitation-free operation several design parameters are required. The upstream conduit diameter should be a minimum of 1.2 times the seal ring orifice diameter; but if that is not possible, a tapered expansion can be designed into the upstream body of the jet-flow gate valve to achieve the 1.2 expansion. The U.S. Bureau of Reclamation has done considerable research on jet-flow gates. The downstream discharge conduit diameter should be a minimum of 1.4 times the orifice diameter to allow air to flow back into the orifice area of the gate. For submerged service, the downstream conduit should be a minimum of 3 times the orifice diameter. If the discharge conduit is longer than 1.5 times the diameter, air vent(s) should be provided adjacent to the jet-flow gate valve. The discharge conduit is usually fabricated from stainless steel, since it would be difficult to maintain a coating with the high-velocity discharge jet.
At moderate to large gate openings (50 to 100 percent), the discharge jet is fairly well confined; and will plunge into a stilling basin or pool if the gate is set high enough to provide a sufficient drop. If the jet-flow gate valve is set low relative to the downstream pool, the discharge jet will likely bounce across the top of the surface. Figure 9-2 illustrates a 42-inch jet-flow gate valve discharging at 100 percent open with 400 feet (121.9 meter) of head (Note the relatively confined discharge jet, which is typical).

Figure 9-2. Forty-two Inch Jet-Flow Gate Valve, Le Grande Powerplant, Washington  
(Courtesy of Dr. BTA Sagar)

Figure 9-3 illustrates the flow from a 65-inch (1.651 meter) jet-flow gate valve at a small partial opening with 165 feet (50.3 meter) of head.

Figure 9-3. Sixty-five Inch Jet-Flow Gate Valve, Cushman Dam, Washington  
(Courtesy of Dr. BTA Sagar)
c. Design Limitations

Although jet-flow gate valves have been used at heads up to 193 meter (645 feet), there has been no maximum operating head established. Successful operation at very high heads would lead to the assumption that the operating head could go considerably higher, but model testing would be recommended.

9-4. Operating Equipment

Jet-flow gate valves can be operated by manual, electric, or by hydraulic actuators. Pneumatic cylinder operation is not recommended, since it is difficult to attain and maintain a set gate position with a compressible fluid. See Chapter 11 for additional discussion regarding valve actuators.

b. Manual Actuators

Since the jet-flow gate valve operates with sliding disc, a rising stem can be attached to the disc, and a handwheel or gearbox can be provide to operate a threaded stem, similar to that used for slide gates. Manual operation would only be practical for a small jet-flow gate valve, or a moderate size with low head. The operating forces to be overcome include the friction between the disc and body and the friction between the seal ring and disc, as well as the weight of the moving parts. Hydrodynamic forces affecting operation are minimal.

c. Electric Actuators

Electric actuators can be used for all sizes of jet-flow gate valves. See Chapter 11 for a general discussion on the principals and applications for electric power actuators.

d. Hydraulic Actuators

The hydraulic power unit and the hydraulic cylinder need to be matched to the pressure and flow requirements for jet-flow gate valve operation. Counterbalance valves should be provided to prevent downward drifting of the disc with the power unit deenergized. If the jet-flow gate valve is to modulate flow, the hydraulic power unit should include accumulators to reduce hydraulic pump starts and stops. Also, accumulators could be provided for emergency operation without electrical power.

9-5. Installation and Operation Considerations

a. General

Jet-flow gate valves have an excellent history of maintenance-free operation. There are no known documented failures, and repairs have been minimal. Operation in extremely cold climates has not been an issue, other than buildup of ice on adjacent structures due to a fine mist associated with any discharge.
There have been problems with leakage between the seal ring and disc during initial shop assembly when tolerances on all the associated components (body, seal ring, seal ring clamp, disc, etc.) are not monitored carefully. Re-machining the seal ring clamp usually corrects clearance problems, allowing sufficient clearance for the seal ring to maintain contact against the disc.

For installation purposes, jet-flow gate valves have a relatively short flange-to-flange length, but require considerable overhead room for the rising stem and operating system. They can be installed indoors or outdoors; and usually have a support underneath, rather than being supported by the adjacent conduit, although they could be cantilevered from a short conduit if necessary.

Materials of construction should be selected in design with consideration of the water chemistry prior to valve procurement. Site specific operating conditions and limitations should always be considered when designing and installing a water control valve.

**b. Upstream Disturbance**

It is usually recommended that a guard gate or valve be located 3 to 5 diameters upstream of a jet-flow gate valve. Since there is no control component in the flow path of a jet-flow gate valve, flow discharge is generally undisturbed. However, at small openings of a jet-flow gate valve with discharge concentrated along the bottom of the conduit, a close-coupled (less than 3 to 5 diameters upstream) butterfly guard valve may cause flow problems, whereas a full-ported guard valve would not create a flow issue.

**c. Waterhammer**

Waterhammer is always a consideration in flow control, especially with long upstream conduits. Operation of jet-flow gate valves is usually slow enough that waterhammer is not a problem; but for extremely long conduits, waterhammer conditions should be analyzed.

Smaller jet-flow gate valves, 0.15 to 0.6 m (6 to 24 inch), operate at rate of disc movement of approximately 0.15 m per minute (6 inches per minute), resulting in opening or closing times of 1 to 4 minutes. Larger jet-flow gate valves, over 0.6 m (24-inch), usually operate at 0.3 meter per minute (1 foot per minute). For finer flow control some installations have used slower operating speeds.

**d. Cavitation**

Due to the inherent flow characteristics as water passes through a jet-flow gate valve, there is very little cavitation potential. As water passes through the seal ring orifice, the flow jet contracts and draws in air (through the discharge conduit), which prevents sub-atmospheric pressure from occurring.
e. Testing

There are no detailed testing instructions provided in this document, but the installer should follow shop and field testing of each jet-flow valve in accordance with industry practices and specification requirements.
CHAPTER 10 – KNIFE GATE VALVES

10-1. Application

Knife gate valves used in outlet works as guard valves or regulating valves has increased in recent years. The basic design of a knife gate valve includes a thin sliding disc, relatively smooth flow path, and short flange-to-flange dimensions; which makes a knife gate valve an excellent guard gate in an outlet works conduit. Since there is very little inherent flow disruption, knife gate valves can be closely coupled to downstream regulating gates or valves. Figure 10-1 illustrates a typical knife gate valve.

With some modifications, throttling knife gate valves have excellent potential for use as a regulating gate for moderate heads less than 30 meter (100 feet) and for outlet works with anticipated limited use, instead of using a more expensive jet-flow gate valve or fixed-cone valve. A throttling knife gate valve uses an expanded discharge conduit, with the diameter being approximately 1.3 or more times the valve diameter. The discharge pattern is similar to jet-flow gate valve, since the downstream conduit is usually 1.0 to 1.5 diameters long, and can be longer if air vents are provided. Figure 10-2 illustrates a throttling knife gate valve for 65 feet (19.8 meter) of head with a 54-inch (1.372 meter) diameter discharge conduit.
10-2. Sizes and Heads

Knife gate valves for guard valve service have normally been manufactured from 2 inch (50.8 mm) to 84 inch (2.134 meter) diameter, and can be designed and manufactured in larger sizes. Flow losses through a knife gate valve are negligible, since there is very little flow disruption through the sealing area and fluidway.

Knife gate valves for throttling service have had limited use, but are available in the same sizes as the standard knife gate valves. Most throttling knife gate valves have been used for heads less than 30 meter (100 ft.), but there have been some installations up to 41 meter (135 feet). The coefficient of discharge for a fully-opened knife gate valve has not been accurately determined to a precise valve for all valves and percent openings; however, according to DeZURIK, for 6-inch (0.152 meter) to 36-inch (0.914 meter) valves that are fully open the K head loss coefficient ranges from 0.120 to 0.096, respectively. The K head loss coefficient, as used in Equation 2.1, for each valve operating condition should be evaluated and confirmed, if possible, by the valve manufacturer.
10-3. Design Considerations and Limitations

Knife gate valve bodies are usually fabricated from welded carbon steel plates and shapes; frequently using a stainless steel liner for all the wetted surfaces. For some installations, the entire knife gate valve can be fabricated from stainless steel. The disc and stem are usually stainless steel, for good corrosion and cavitation resistance. As with many other valves, knife gate valves can be manually or electric motor operated with rising stems, or operated by hydraulic cylinder.

The knife gate valves can be of several body styles such as a very thin wafer body with tapped holes for attaching to the adjoining conduit flanges, or an extended flange body with standard conduit flange connections.

Sealing surfaces can be with metal-to-metal seats, if drop-tight leakage is not required. Resilient seats can be used where leakage is a concern. Knife gate valves can be designed for upstream or downstream sealing, depending on the application.

Knife gate valves are available in bonnetless or bonneted form. Bonnetless knife gate valves use an exposed upper housing with a rectangular seal around the sliding disc. If knife gate valves are exposed to the elements, the seal around the disc may be troublesome due to ice, dirt, and debris. Bonneted knife gate valves have a housing over the sliding disc, with a stem seal where the operating stem penetrates. The bonneted style is more appropriate for use in a dam outlet works.

Figures 10-3, 10-4, and 10-5 at the end of section illustrate several variations in design for knife gate valves. Custom design variations can be provided by several manufacturers to suit particular applications. A 60-inch (1.524 meter) knife gate valve was recently designed and fabricated from stainless steel with a stainless steel hydraulic cylinder and dual bonnets for underwater installation in the horizontal position over a vertical intake according to Hilton Valve Inc. (now DeZURIK).

The maximum operating head for knife gate valves has not been established. The maximum velocity through a knife gate valve has not been established either. With no real obstruction in the flow, as with a butterfly valve, knife gate valves are capable of smooth operation at almost any velocity encountered in an outlet works conduit with a regulating valve downstream. There have been no noticeable cavitation problems with the throttling knife gate valves presently in use.

10-4. Operating Equipment

Knife gate valves can be operated by manual, electric, or by hydraulic actuators. Pneumatic cylinder operation is not recommended, since it is difficult to attain and maintain a set gate position with a compressible fluid. See Chapter 11 for additional discussion regarding valve actuators.
10-5. Installation and Operation Considerations

There are no detailed installation and operations considerations provided in this document, but the general installation and operational considerations would be followed and shop and field testing of each knife gate valve should be in accordance with industry practices and specification requirements.

Materials of construction should be selected in design with consideration of the water chemistry prior to valve procurement. Site specific operating conditions and limitations should always be considered when designing and installing a water control valve.
Figure 10-4. Bonneted Knife Gate Valve with Extended Flanges (Courtesy of Hilton Valve Inc. now DeZURIK)

Figure 10-5. Bonneted Knife Gate Valve with Extended Flanges and Oversized Outlet (Courtesy of Hilton Valve Inc. now DeZURIK)
11-1. Valve Operating Systems

a. General

There are several types of operating systems available to operate valves. Principally, there are four basic types: manual actuators, electric-motor actuators, hydraulic actuators, and pneumatic actuators.

Powered actuators can be powered with a supply medium of air, water, or oil. Air is an economical and reliable power supply medium; however, it should be limited to smaller valves according to AWWA Manual M66 (AWWA, 2015). Water is also a common power supply medium; however, depending on the plant application there may not be a reliable source of water and there are also long term corrosion concerns according to AWWA M66.

Design of the valve operating system should consider the power requirements, operation and maintenance requirements, and installation limitations. Installation limitation include position of the actuator cylinder or stem (horizontal or vertical), available headroom or ceiling clearance of the housing structure and future maintenance clearance requirements.

b. Manual Actuators

Manual operation is usually accomplished with a crank or handwheel connected to the valve operating mechanism via threaded stem or gearbox arrangements. Some sleeve valves and butterfly valves use a rising stem design, where a threaded stem is raised or lowered to open or close the valve disc. The stem has threads machined onto the upper end, and a crank, handwheel, or gearbox is connected to the stem through an operating nut.

The gear actuator produces the quarter-turn rotary motion for valve opening or closing. The actuators have full enclosed gearing and are designed to generate adequate torque to seat, unseat, and rigidly hold the valve disc at any intermediate open or closed position. The actuators are provided with adjustable, mechanical, stop-limiting devices to prevent over travel of the valve disc in open and closed position.

The gear actuators are self-locking and designed to transmit twice the actuator rated output torque without damage to the faces of the gear teeth or the contact faces of the screw or nut. Manual gear actuators are governed by the AWWA Standard C 504; which requires the actuators to be designed to produce the required operating torque with a maximum rim pull of 360 N (80 lb) on the hand wheel and a maximum input of 200 Nm (150 ft-lb) on wrench nuts (AWWA, 2010a).

Fixed-cone valves, and some sleeve valves and butterfly valves use a linkage arrangement to convert rotary motion from the crank, handwheel, or gearbox to linear
motion. The crank or handwheel should be sized to operate easily and provide sufficient force to operate the disc. Handwheels should be at least 0.3048 to 0.381 m (12 to 15 inches) in diameter for ease of turning. Equipment with cranks or handwheels is usually designed to operate with no more than 180 N (40 pounds) of pull on the handle or handwheel rim.

However, the equipment must be designed for much more effort, 360 to 540 N (80 to 120 pounds), since operating personnel can exert much more than 40 pounds effort if the equipment is stuck or difficult to operate. The size of equipment using manual operation should be carefully considered. Although some valves can be operated manually, operation may be so slow that it is not practical and if operation is too difficult, the equipment will not be exercised, as it should.

Manual operators may be available with a hand-wheel, chain-wheel, or square-nut options.

c. Electric-Motor Actuators

Electric-motor actuators are used in a similar manner as manual actuators, that is, either linear motion with threaded stems or rotary motion converted to linear motion. An electric-motor actuator consists of a high-torque electric motor, gearbox for suitable speed reduction, pushbuttons, limit switches to control stopping positions, torque switches to protect equipment from overloads, indicating lights, local position indicators, and in some instances remote position indicators. The high-torque electric motors are used to initially start equipment open or closed, and operate best on three-phase power due to the high-current draw during starting. Motor-actuators will function on single-phase power, but size and output is limited. Motor-actuators are usually designed for outdoor service, with weatherproof enclosures. Submerged operation is usually not an option, except for extremely short duration. Handwheels are usually provided on motor-actuators for manual operation if primary power is interrupted and/or emergency back-up power source malfunctions.

Electric actuators are usually designed to meet the requirements of AWWA. The AWWA C542 standard describes electric motor actuators that are externally mounted on gate, ball, plug, cone, globe and butterfly valves and on slide gates (AWWA, 2016b). Electric actuators can be rated to produce not less than the required operating forces anticipated.

An electric actuator for rising stem applications should include as one integral unit, the electric motor, reduction gearing, threaded drive nut, limit switches, torque switches, gear case, and auxiliary handwheel. Gear reduction is accomplished by means of helical, bevel, and/or worm gears. Electric actuators are usually self-locking.

The gears and shafting are supported on antifriction bearings. All gearing and bearings should be grease or oil lubricated. Seals should be provided at all shaft penetrations of the gear case to prevent leakage of lubricant and entrance of dirt or contamination.
Electric actuators are equipped with open and close limit switches and should be of field adjustable type, capable of being set either in fully open, fully closed, or at any intermediate position. Also, electric actuators should include adjustable torque switches to prevent overloading the components during valve operation. All quarter turn actuators should be equipped with independently adjustable stop limiting devices to establish over travel protection at both the fully open and fully closed positions. Stops must be externally adjustable and properly sealed to prevent the entrance of moisture or other contaminants.

For open-close and throttling service, a reversing starter should be provided. Push buttons or selector switch need to be provided.

The electric-motor type actuators produce a multi-turn rotary motion or are used to operate a gear head drive for quarter-turn applications. In addition, actuators used for modulating service should be rated to produce not less than twice the required valve dynamic torque. Motors should be sized for 1.5 times the actuator torque requirement.

The motor actuator for quarter-turn applications should include as one integral unit, the electric motor, reduction gearing, drive coupling between the final drive gear and valve stem, torque switches, position limit switches, gear case and auxiliary hand wheel. The quarter-turn actuator can be furnished in either of the following two styles:

- multi-turn actuator directly coupled to an auxiliary final drive gear box or
- combination of the electric actuator and final drive gear assembly in one housing.

In either case, the valve and actuator combination must be self-locking. Reduction is accomplished by means of spur, helical, bevel, and/or worm gears.

When required by the unseating application, a lost motion device independent of gear backlash should be supplied as an integral part of the actuator gear train. This device allows the motor to attain full speed before the load is engaged. This lost motion device is not incorporated in actuators supplied for modulating service.

d. Hydraulic Actuators

Hydraulic cylinder and vane type actuators are usually designed to meet the requirements of AWWA. The AWWA C541 standard describes hydraulic actuators that are externally mounted on gate, ball, plug, cone, globe and butterfly valves and on slide gates (AWWA, 2016a). The AWWA Manual of Water Supply Practice M66 presents the general principals used for selecting, sizing, and installing hydraulic and pneumatic actuators. Hydraulic and pneumatic actuators can be rated to produce not less than the required operating forces anticipated (AWWA, 2015).

Hydraulic operation is most often used on large valves operating at high heads, but is becoming more common for small valves at low heads. Hydraulic actuators consist of a
cylinder-actuator, driver media (oil, water, etc.), motors, pumps, accumulators, controls, and ancillary equipment. Hydraulic actuation typically uses one or more hydraulic cylinders to provide linear motion to the valve control mechanism. The hydraulic cylinder(s) are connected to a central hydraulic power unit (HPU) via rigid hydraulic lines and flexible connections. The hydraulic line connections should be welded where possible, to reduce potential for leaks at joints. Hydraulic cylinders can be made relatively compact, since high operating pressures are readily available 13.8 to 20.7 mPa (2,000 to 3,000 psi), with systems capability approaching 34.5 mPa (5,000 psi). AWWA requires the cylinders be suitable for operating pressures up to a maximum of 2,500 psi (17.2 mPa) and have a minimum burst pressure of 10,000 psi (68.9 mPa).

Hydraulic cylinders should be tie-rod or bolted flange construction, and be governed by ANSI B93.15 and ANSI B93.10 for mounting configurations and pressure ratings. The cylinders are manufactured in accordance with the standards of the National Fluid Power Association (NFPA). Hydraulic cylinders can be designed for submerged operation, and can be furnished with electronic sensors for remote valve position sensing. All static and dynamic seals should be pressure energized and should be compatible with the hydraulic fluid used. Hydraulic cylinders are usually made of steel, with chrome plated, high-strength stainless steel rods.

Hydraulic actuators could be oil or water media operated, although the most common fluid used is hydraulic oil.

**Oil Hydraulic Actuator** - Oil hydraulic cylinders are of tie rod, bolted flange or welded construction. The cylinder mounting dimensions comply with the requirements of ANSI B93.15. Cylinder pressure ratings are determined per ANSI B93.10. All static and dynamic seals should be pressure energized and should be compatible with the hydraulic fluid to be used. Cylinders should be equipped with adjustable flow control devices to control the piston rod speed.

**Water Hydraulic Actuator** - Water hydraulic cylinders are of tie rod or bolted flange construction. They are governed by ANSI B93.15 and ANSI B93.10 for mounting and pressure ratings. The material of the cylinder barrel should be bronze, fiberglass-reinforced plastic, or stainless steel. The inside surface of the barrel should have a 0.5 micron (20 microinch) finish or smoother. The head and caps should be of bronze. The piston should be bronze and piston rod should be chrome plated stainless steel. All seals should be of non metallic elastomeric material suitable for water service and the piston seals should be of a pressure energized design. Cylinders should be equipped with adjustable flow control devices to control the piston rod speed.

HPUs consist of an oil reservoir, one or more electric-motor driven hydraulic pumps, control valves, filters, pressure switches to control pump and valve operation, relief valves to limit operating pressure, and sometimes accumulators to store pressurized hydraulic oil. HPUs can be designed to operate more than one valve at a facility, by simply adding the required control valves, and can be located at relatively long distances from the valve equipment being operated.
Manual operation can be provided by using a hand-pump system attached to the HPU. Also, hand pump provides operation capability during electric power interruption. Hand pumps may be used to provide slow operating speeds; but some two-stage pumps may be used for larger output at low pressure, if desired.

Accumulators provide operating flexibility for limited service during electric power interruption, or for modulating service without having to run the hydraulic pumps and motors for every valve movement.

Improved hydraulic oils can provide better outdoor performance, and biodegradable oils are available to address environmental concerns. Some older valves operated by hydraulic systems use water instead of hydraulic oil. The water is stored in tanks above the dam, or the pressure is built-up by pumps. The principles are the same, but the water systems are usually manually operated by opening and closing control valves. Water systems have operated for many years and some are still in service. However, corrosion, worn and corroded seals, and leaky piping have made many of the water systems lacking in reliability. Many of the water system components, such as cylinders, are very large since high pressure produced in oil hydraulic systems is not available. Most water systems operated in the range of several hundred psi, instead of several thousand psi for an oil hydraulic system.

e. Pneumatic Actuators

Pneumatic actuators are similar to hydraulic actuators; except, the driver media is air. Pneumatic actuators are rarely used for operating valves. The problem with pneumatic operation for valves is that with air being compressible, it is difficult to maintain a set valve position. If operating forces are high, pneumatic cylinders and control systems become quite large, since air pressure is usually limited to approximately 862 kPa (125 psi). Moisture in compressed air can create operating problems at cold temperatures, and can cause internal corrosion of pneumatic equipment. Also, compressed air is dangerous because uncontrolled expansion of air when released can cause great damage.

Pneumatic cylinders should be of tie-rod or bolted flange construction with a pressure rating of 150 psi minimum. Cylinder mounting dimensions should comply with applicable requirements of ANSI B 93.15. The cylinder barrel should be bronze, fiber glass reinforced plastic, carbon steel, stainless steel, or hard drawn brass. The inside surface of the barrel should have a 0.5 micron (20 microinch) finish or smoother. Cylinder heads and caps should be carbon steel, suitable nonmetallic material or ductile iron. Pistons should be stainless steel, carbon steel, suitable nonmetallic material, or ductile iron. The piston rod should be carbon steel or stainless steel and should be hard chrome or electrolysis nickel plated. The seals should be elastomeric materials suitable for air service.
For operation of quarter-turn valves, an intermediate mechanism is required to convert the cylinder’s linear output to the required rotary motion. Typical methods of conversion are lever, link/lever, rack and pinion, and scotch yoke.

f. Controls

Controls are similar for motor, hydraulic, and pneumatic actuators and consist of “open-stop-close” push buttons for each actuator and an emergency push button. If specified, the actuator can be remotely operated. Indicator lights are provided on each actuator to relay open-close light indications for valve position. Color code system for the indicator lights varies by manufacturer. If position indicators are required, then an indicator dial should be integral to the actuator and in coordination (“full-step”) with valve travel during powered or manual operation.

The electric controls for an actuation system include motor starters, push buttons, indicator lights, local disconnect, selector switches (on-off, local-remote), terminal strips, space heater, limit switches, torque switches, etc. and should be housed in a specified NEMA-rated enclosure integral to the actuator.

11-2. Remote Operation

a. General

More and more designs are being prepared with remote valve position indication and remote or automated valve operation. The modern operating systems have reasonably inexpensive means of providing remote position indication, consequently remote and/or automated control is more attractive. Better control of water flow can be provided by remote and/or automated control, since there is faster response to changing flow conditions. Also, remote operating systems have become more reliable.

b. Electric-Motor Actuators

Electric-motor Actuators can be furnished with position transducers producing a 4 to 20 Ma signal that provides a continuous output signal of valve position. This signal can be transmitted by hard wire, optic cable, or radio signal to a control panel or computer many miles away. The transducers are built into the actuators for integral operation, and can be easily modified to produce stepping functions or signals at selected valve positions.

c. Hydraulic Cylinders

Hydraulic cylinders can be provided with linear position transducers producing a 4 to 20 Ma signal that function just as the transducers on the motor-actuators, providing a continuous output signal of piston rod travel that can be correlated to valve position.
11-3. Alarms and Instruments

The following features should be included in the valve control system to provide long-term reliable system operation:

- indication of valve "Open" and “Closed” positions;
- trip switch or limit switches to deenergize the hydraulic/electrical control system when valve reaches fully open and fully closed positions;
- visual and audio alarms indicating selected equipment malfunctions;
- provision to prevent sudden valve closure which can cause excessive waterhammer and conduit rupture;
- measure differential head to prevent operation of valves not designed to open/close against differential head, as in a selective withdrawal system; and
- provision for Quick Shutoff of turbine guard valve within the time specified by turbine manufacturer.
APPENDIX A – REFERENCES

1. AWWA; “Rubber-Seated Butterfly Valves, 3 In. (75 mm) through 72 In. (1,800 mm)”, Standard C504, 2010a.

2. AWWA; “Large-Diameter Rubber-Seated Butterfly Valves, Size 78 In. (2,000 mm) and Larger”, Standard C516, 2010b.


24. Hartman, Tom, Lindsey, Keith E. PhD; “Development of Constant Velocity, Multijet Sleeve Valves”


30. Lindsey, Keith E. PhD; “Application of Multijet Sleeve Valves” Lindsey Fabrication, Inc Valve Div, Azula, CA.

31. Maynord, Stephen; “Fixed-Cone Valve, New Melones Dam, California,” Army Engineer Waterways Experiment Station Vicksburg, MS Hydraulics Lab Technical Report HL-81-4, January 1981.


APPENDIX B – INSPECTION and TESTING GUIDELINES


a. General. General Inspection Guidelines was developed based on a White Paper prepared by Mr. Chuck R. Cooper for the May 2004 FEMA Outlet Works Workshop (Cooper, 2004). It was developed for inspection of Outlet Works; and since large valves are installed in many other facilities with conduits and penstocks as shut-off devices, it has been adapted for inclusion in this report.

b. Trained Inspector. Defects and deterioration develop progressively over time. A trained and experienced inspector can identify defects and potential problems before existing conditions become serious.

c. Frequency of Inspection. Periodic inspection may reveal trends that indicate the development of more serious problems. Inspection intervals may vary depending on the overall conditions determined from previous inspections and the existence of any dam safety concerns. Periodic inspections can vary in scope and purpose, and by the organization or personnel dam operator, agency/district level, etc.) performing the inspection.

d. Types of Inspections. Dam safety organizations and dam owners may employ a variety of inspections during the life of a facility. These inspections may include the following types based on Reclamation Inspection of Spillways and Outlet Works (Reclamation, 1988a):

   Initial or formal. – Initial or formal inspections include an in depth review of all pertinent data available for the facility to be inspected. Design and construction data are evaluated relative to current state-of-the-art to identify potential dam safety problems or areas requiring particular attention. A thorough onsite inspection of all features is conducted, and an attempt is made to operate all mechanical equipment through their full operating range, if possible.

   Periodic or intermediate. – Periodic or intermediate inspections are conducted between formal inspections. An in-depth review is made of all pertinent data available for the facility to be inspected. However, the data review focuses on the current condition of the equipment; the data are not evaluated relative to current state-of-the-art criteria. A thorough onsite inspection of all features is conducted. Not all mechanical equipment may be tested during any one inspection. Some equipment may be operated at another time or during the next inspection.

   Routine. – Routine inspections are typically conducted by field or operating personnel. The primary focus is on current condition of the equipment. Available data may not be reviewed and evaluated prior to the inspection, depending on the inspector’s familiarity of the equipment. Inspections may be scheduled on a regular basis or performed in conjunction with other routine tasks.
Special. – A special inspection is conducted when a unique opportunity exists. For example, if low water conditions in a reservoir expose a normally inundated structure, a special inspection may be arranged.

Emergency. – An emergency inspection is performed when an immediate dam safety concern is present or in the event of an unusual or potentially adverse condition (e.g., immediately following an earthquake).

e. Scheduling of Inspections. Scheduling of periodic outlet works inspections may be influenced by the following according to Reclamation Preparing to Conduct a Dam Safety Inspection (Reclamation, 1988b):

Sufficient notice. – Dam owners and operators may need sufficient time to make necessary arrangements, such as pre-inspections associated with lockout/tagout and confined space entry, or special equipment or approval for unwatering conduits, terminal structures, or pools, etc. This process could require several weeks or months depending on the facility.

Scheduling access. – Access for the inspection should be scheduled when most or all of the major components of the outlet works system can be examined. Some features such as intake structures and upstream conduits are usually submerged and not accessible. Downstream conduits and terminal structures may or may not be unwatered and accessible for inspection. The dam owner or operator may be requested to provide notification when reservoir conditions permit or when the reservoir can be drawn down to allow the inspection to be performed. If the feature to be inspected is normally inundated and inaccessible, certain factors discussed in Reclamation Technical Memorandum 6 (Reclamation, 1985) and Review/Examination Program for High- and Significant-Hazard Dams (Reclamation, 2001) should be considered in determining the extent and frequency for inspection such as:

- Results of previous “hands on” inspection or evidence from the inspection of the normally accessible portions of the feature. Inspection of the normally accessible portion of a feature may provide information on the probable condition of the inaccessible portion.
- Operational history and performance of the feature, since its previous inspection,
- Relative costs for providing access for inspection of the feature, including costs associated with lost water and power revenues.
- Age of the feature.
- Changes in standards or guidelines, design criteria, or features during construction.
- Critical function of the feature.
- Any site conditions which exist that may compromise the safety of the feature.

Operation. – Certain problems may not normally appear when the feature is dry that appear when the feature is being operated. Also, when a feature is operating during a period of higher than normal releases information may be provided that may not have been available during previous inspections.
The opportunity to optimize both access and operation during a single inspection typically is not possible. Inspection objectives may have to alternate from one inspection to the next. This may necessitate the need for scheduling “special” inspections during unusual conditions, in addition to periodic and routine inspections to provide a comprehensive view of the outlet works safety. Special inspections may be required after floods, seismic activity, or other unusual events.

**f. Preparation and Planning.** The success of an inspection will be dependent upon good preparation and planning. Any inspection should consider the following:

- **Selection of inspection team.** – Members of the inspection team will vary depending on the needs and resources of the organization or dam owner, type of the inspection, results of the data review, and any special requirements.

- **Review of project data.** – The amount of available data may vary greatly from outlet works to outlet works. The extent of project data review and evaluation depends on the type of inspection to be conducted.

- **Preparation of an inspection plan.** – A detailed inspection plan should be prepared to identify all features to be inspected, problem areas, and areas of potential problems. Also, the inspection plan should identify special logistics, access, or equipment requirements. An inspection checklist is typically prepared as part of an inspection plan. The checklist is used to identify specific inspection objectives and is useful in developing the final inspection report.

**g. Inspection Method.** Methods used for the inspection of the various features of an outlet works are mainly dependent upon accessibility. The following factors influence accessibility.

- **Inundation.** – Reservoir operations and water levels may make some features unavailable for normal inspection and require specialized inspection services (e.g., divers, remotely operated vehicles (ROV)).

- **Confined space.** – Certain features may require Occupational Safety and Health Administration (OSHA) confined space permitting for man-entry, lockout/tagout procedures, and preparation of a Job Hazard Analysis (JHA). An alternative to man-entry is the use of specialized inspection services (e.g., closed circuit television (CCTV)).

- **Size constraints.** – Limitations in size may prevent man-entry and require specialized inspection services (e.g., CCTV).

- **Specialized Inspection.** - Specialized inspection includes the use of divers, ROV, and CCTV.
B.2. Inspection and Testing Recommendations


b. Butterfly Valves.

Inspections - The following list identifies items that should be checked for damage or malfunction, and suggests a frequency of safety examinations.

Valve Actuator (every 2 years)

- Look for damaged or broken parts on actuators; corroded, dirty, or loose contacts, frayed wiring, or broken components on electrical devices; and leaking oil from packings, conduits, pumps, valves, and gages on oil hydraulic systems.

Valve Body and Disc (every 2 years)

- Exterior. Look for cracked, broken, heavily corroded, missing parts and water leakage around flanges and seal-adjusting screws.
- Interior (42 inch (1.067 m) and larger). Look for damage from cavitation, wire drawing, corrosion, or any other defects in the fluidway or on the seals, and excessive leakage as defined by AWWA when valve is closed and subjected to full head.
- Disc (42 inch (1.067 m) and larger). Look for cavitation damage, especially on the downstream face of the disc where negative pressures are apt to occur when the valve is throttling flow during closure. Look for wire drawing around the trunnions.

Operational Tests - The following tests should be performed to confirm the ability of the valve to operate as intended and suggests a frequency of the operational tests.

- Operate the valve through full travel under balanced head conditions (no flow) and ensure that the valve, actuator, and controls function properly without vibration/noise or binding (every year).
- Operate the valve through an emergency closure test with full flow at maximum head, if possible, and ensure that the valve, actuator, and controls function properly. Before closing, ensure adequate venting is provided and the airway is clear (every 10 years).
- Measure leakage on valves less than 42 inch (1.067m) diameter. Excessive leakage as defined by AWWA may indicate cavitation or erosion damage requiring removal or repair (every 2 years).
c. Fixed-cone Valves

Inspections – The following identifies items that should be checked for damage or malfunction, and suggests a frequency of safety examinations:

Valve Actuator (every 2 years)

- Look for damaged or broken parts on manual and motorized actuators; corroded or dirty contacts, frayed wiring, or broken components on electrical devices; and leaking oil from seals, conduits, pumps, valves, and gages on oil hydraulic systems.

Valve Body and Sleeve (every 2 years)

- Exterior. Look for cracked, broken, heavily corroded, or missing parts and excessive leakage as defined by AWWA when the valve is closed and subjected to full head.
- Interior. Look for damage to fluidway surfaces caused by corrosion or cavitation. Also check internal ribs for signs of fatigue failure, e.g. cracking, caused by vibration.
- Sleeve. Look for damage to seating surfaces and finished surface against which packing bears.

Operational Tests – The following test should be performed to confirm the ability of the valve to operate as intended:

- Operate the valve through full travel under full design head, if possible, and ensure that the valve, actuator, and controls function properly without chattering or binding. There should be no excessive vibration produced by the flow. (every year).

d. Sleeve Valves

Inspections – The following identifies the items that should be checked for damage or malfunction, and suggests a frequency of safety examinations.

Valve operator (every 2 years)

- Look for damaged or broken parts on manual and motorized operators, corroded or dirty contacts, loose connections, frayed wiring, or broken components on electrical devices; and leaking oil from seals, conduits, pumps, valves and gages on oil hydraulic systems.

Valve body and sleeve (every 2 years)
• Exterior. Look for cracked, broken, heavily corroded loose or missing parts, and cavitation or erosion damage to baseplate, supports, floatwell liner, baffles and ports.
• Interior. Look for plugged of or damaged ports on multi-jet valve, cavitation or erosion damage to the cone, stem, and stem supports. Check condition of packing and gland.
• Sleeve. Look for damage to bottom seating edge and finished surface against which the packing bears. Check connector to stem. Ensure that stem nuts are tight and locked.

Operational Tests – The following tests should be performed to confirm the ability of the valve to operate as intended:

- Operate the valve through full travel under balanced head conditions (no flow) and ensure that the valve, actuator, and controls function properly without chattering or binding (every year).
- Operate the valve under full design head, if possible, to an opening that gives the maximum design discharge of the outlet and ensure that the valve, actuator, and controls function properly. No excessive vibrations should be produced by the flows (every 2 years).

c. Spherical Valves

Inspections – The following identifies the items that should be checked for damage or malfunction, and suggests a frequency of safety examinations.

*Valve Actuator* (every 2 years)

- Look for damaged or broken parts on the mechanical actuators; corroded or dirty contacts, loose connections, frayed wiring, or broken components on electrical devices; and leaking oil from seals, conduits, pumps, valves, and gages on oil hydraulic systems.

*Valve Body and Sphere* (every 2 years)

- Exterior. Look for cracked, broken, heavily corroded, loose, or missing parts and excessive leakage from any of flanged joints or valve components.
- Interior. Look for damage to fluidway surfaces caused by corrosion or cavitation. Also check for excessive leakage when the valve is closed and subjected to full head.
- Sphere. Look for damage to seating surfaces and the finished surface against which the packing bears. Check condition of seals

Operational Tests – The following tests should be performed to confirm the ability of the valve to operate as intended:
• Operate the valve through full travel under balanced head conditions (no flow) and ensure that the valve, actuator, and controls function properly without chattering or binding (every year).

• Operate the valve through an emergency closure test with full flow at maximum head, if possible, and check that the valve, actuator, and controls all function properly (every 10 years).
APPENDIX C – OTHER VALVES

The focus of Appendix C is to provide a discussion on “other” types of commonly used valves that are not discussed in detail in this report. An additional source for description of these other commonly used valves is Design and Selection: Valves, Hydrants, and Fittings (Stiver, 1968). These other fluid control valves included the following types:

- Ball
- Gate
- Globe
- Diaphragm and Pinch
- Check
- Relief and Surge Protection
- Mokveld

**Ball Valve.** Ball valves have been used in a variety of hydraulic facilities since the 1960’s. Ball valves are usually used for shutoff applications, essentially preventing flow or allowing all flow to pass through the valve. A typical ball valve consists of a spherical, internal component, referred to as the “ball,” which can be rotated to control flow of fluid. The ball contains a port or hole through the middle of the ball, allows flow to pass when the port is inline with both ends of the valve. Conversely, when the port is perpendicular to the ends of the valve, the ball prevents the passage of flow and provides a watertight seal.

There are two main varieties of ball valves: the floating-ball valve and the trunnion-mounted ball valve. The difference in the two varieties of valves consists of the way the ball is supported. Floating-ball valves are supported by two seat rings, one around each end of the valve. Floating-ball valves are typically used for smaller valves, up to about 8 inches. Trunnion-mounted ball valves are used when larger sizes are required. Trunnion-mounted ball valves provide a more complete support of the ball by anchoring the ball at both the top and bottom with trunnion mounting pins.

Ball valves have traditionally been manufactured by a casting process that involved pouring cast iron into a ball-shaped mold. This process has disadvantages; namely, air bubbles frequently form inside the ball during the casting process. Additionally, the ball must be intentionally cast thicker than desired to account for the lathing processing that is required after casting to remove surface pores. This can compromise the ability of the ball to form a water-tight seal. More recently, a new method of processing ball valves has been adopted that consists of forging two symmetrical ball valve halves. These halves are then welded together using friction welding. Any ribs formed during the welding process are removed by mechanical punching.

Ball valves have been proven so effective and durable that they have essentially become the valve of choice for most small shutoff applications, replacing gate and globe valves previously used for this purpose. In most instances, ball valves achieve perfect flow shutoff, even after years of inactivity. While ball valves are a good choice for shutoff
applications, they do not provide the fine control required for regulating or throttling flow. Also, at partial openings the port becomes a flow restriction that results in a significant pressure drop as flow passes through the valve. Major disadvantages for selecting ball valves includes high manufacturing and installation costs and the valve body is typically much larger than comparable valves.

\[ \text{Gate Valve.} \] - The basic principal of a gate valve is that it opens and closes by lifting a round or rectangular sized disc out of the path of the fluid. The gate valve is sometimes referred to as a sluice valve. For most gate valves, the disc is moved vertically through guide ribs, which are required to prevent rotation of the disc. In the closed position, the disc abuts the seat surface at each of the valve, forming a seal. Consequently, the effectiveness of the valve is determined by the tightness of the seal at the seat-disc interface.

Gate valves are typically characterized by two main areas of design: the disc-lifting mechanism and the type of disc. The disc in a gate valve is generally actuated by a rotating stem. There are two main types of stems, the rising stem and the non-rising stem. Non-rising stems consist of a stem that is threaded into the disc that rotates vertically on the stem while the stem remains in place. Non-rising stems are beneficial where vertical space is limited, as often is the case in many confined valve vaults. Rising stems consist of a disc mounted to the lower end of a stem that moves vertically with the stem. The stem rises out of the valve as it opens. Rising stems are used when it is beneficial to immediately known if the gate is open or closed.

Many types of discs have been used in gate valves throughout the years. Commonly used disc types include solid wedge, flexible wedge, split wedge, and parallel disc. A solid wedge consists of a one-piece wedge shaped component that sits in the seat of the valve to provide a tight fit. Solid wedges are frequently used for turbulent flow applications; but can bind in high temperature applications. In this case, a flexible wedge is used. A flexible wedge consists of a one-piece wedge shaped component that contains a slot or groove on its periphery to allow for flexing under a variety of conditions. A split wedge consists of a two-piece wedge, with each piece adjusting to the adjacent seat ring. Due to this flexibility in providing a seal with both seating surfaces, split wedges are often used in large valve applications. The main disadvantage of the split wedge is that it can collect sediment and debris in between the two disc halves, which may present maintenance and operations problems for use in “dirty” water applications.

A knife gate valve (Chapter 10) is a special type of gate valve. A knife gate valve assembly is similar to that of a traditional gate valve with the exception that the disc contains a sharp edge. Knife gate valves are often used for “dirty” water or slurry applications, as the sharp edge of the disc is able to penetrate through deposits and sediments to form a tight seal against the metal seat.

Gate valves are designed to be used for on/off applications. While ball valves are frequently the valve of choice for small on/off applications, gate valves are typically used when a large valve is required due to their cost effectiveness. One of the main
advantages of a gate valve is that it provides little or no leakage when the proper disc is selected and mates to the seat ring. In addition, the gate valve causes minimal flow restrictions when it is fully open, which results in a very small drop in pressure through the valve. Gate valves also are excellent choices for preventing waterhammer formation in a conduit due to the slow closure/opening time resulting from the stem rotation.

Gate valves are usually not suitable for regulating or throttling flow applications. When a gate valve is used for throttling purposes, the disc is lifted to provide a partial opening. Under the high velocity conditions generally associated with throttling flow, the disc may vibrate against the seat and eventually compromise the ability of the seat to form a water-tight seal.

_Globe Valve._ - Globe valves were one of the earliest types of valves to be used for water control and, as a result, have been used for a variety of applications including shut-off and throttling. A typical globe valves consist of a spherical body containing internal baffles, usually one at each end of the valve. When a moveable disc is lowered onto the baffles, the baffles act as a seat and a seal is formed. When the disc is raised, the opening through the baffles allows for the passage of flow. The disc is generally connected to a stem which controls the vertical movement.

Modern globe valves use one of three types of discs: a ball disc, a composition disc, or a plug disc. The ball disc is spherical in shape and sits on a flat, tapered seat. Ball discs are primarily used for shut-off and low pressure applications. The composition disc consists of a nonmetallic ring insert that is attached to a tradition disc to create a tight seal against the seat. Compositions discs are used primarily for high temperature applications, as well as “dirty” water applications. The ring inserts are generally resilient enough to close on sediment and debris and can be replaced as necessary. A plug disc is a long, tapered disc that is used primarily for throttling flow. The tapered shape permits fine control of the flow by providing a long throttling path, which dissipates energy more gradually.

There are three main types of globe valve bodies: straight-flow, angle-flow, and cross flow. Globe valves typically contain two ports, an inlet and an outlet. When these two ports are oriented directly across from each other, the globe valve is referred to as having a straight-flow body. Straight-flow bodies are the traditional globe valve configuration and can be used for a majority of applications. When the two ports are oriented 90 degrees from each other, the globe valve is referred to as having an angle-flow body. Angle-flow bodies are useful as they function as both a valve and a conduit elbow. Cross-flow bodies contain an additional port that allows for the diversion or combination of flow for a variety of applications.

Globe valves have traditionally been used for both shut-off and throttling applications. Globe valves are frequently used on difficult applications, including long-term throttling applications that contain high pressure drops. Globe valves also offer a precise level of throttling control. Perhaps the biggest disadvantage of using a globe valve is the high energy loss that occurs. As fluid flows through the internal baffles, a significant amount of energy is lost due to both friction and the multiple changes in flow path direction. For
this reason, globe valves have been replaced by ball valves and gate valves for applications that require frequent full flow to occur. Additionally, the amount of space need to assemble the disc is larger than for other valves and can be a restriction in some applications, especially those within valve vaults.

Diaphragm and Pinch Valves. - Diaphragm and pinch valves, unlike other valve types, do not depend on a controlled geometry and rigid materials for closure and flow control. The operation of these valves is dependent on the pressure in the operating chamber above the diaphragm or pinch sleeve regulating the valve opening or closing. The basic control unit consists of a diaphragm, an operating chamber, external piping connected to the operating chamber and the valve body, and various ancillary components depending on valve design such as fixed orifice, gate, and pilot valves.

The diaphragm valve consists of a highly flexible and extensible elastomeric sheet forced down into a rigid edge (“seat”) to cause closer. The chief application of this valve is to comprise the valve body and seating areas of rigid plastic or a metal with corrosion-resistant elastomeric lining to provide a high resistance to corrosive liquids. An additional benefit is for slurries and wastewater applications the valve provides a cushioning effect of the elastomeric diaphragm when providing a tight seal when closed on large and small foreign solids. A disadvantage of the diaphragm valve is the elastomeric diaphragm can crack from repeated flexing or be torn by sharp-edged foreign bodies in the fluid. Also, the contact between the head and diaphragm must be uniform to prevent localized damage to the diaphragm. Damage to the diaphragm could introduce fluid to the bonnet space resulting in corroding of the actuating components.

Pinch valves are similar to diaphragm valves with closure occurring through the squeezing together of elastomeric walls; however, closure occurs over a wide area compared to against a narrow metal ridge like the diaphragm valve. Pinch valves have the ability to operate with fluids that contain abrasives and slurries and have led to wide application over diaphragm valves. The valve is comprised of a flanged elastomeric tube mounted in a split flanged casing connect to typically a compressed air line. Other actuation mechanisms are available, including, mechanical and water. In the fully open position, the elastomeric tube is not constricted and the flow passage is full-port. The valve closure method introduces compressed air into the outer sleeve to narrow the passage with full closure when the elastomeric tube is completely compressed.

Check Valves. - Check valves function differently than all other water control valves described in the report, since the basic function of the check valve is to open and close automatically based on pressure head without operator interference. The primary purposes of a check valve are to prevent reverse flow through the line (one-directional flow) and to cause the valve to automatically close on pressure reversal. The valve is opened or closed by direct force (pressure) with the basic application to provide extra protection against backflow if there is a sudden drop in inlet pressure and to minimize surge. The valve is a two-port valve, meaning there are two openings in the body for fluid to flow into and out of the valve. There are various types of check valves and are used in a wide variety of applications. Specific types of check valves used for water
control applications include the ball, diaphragm, swing, clapper, stop, and lift type check valves. The valves are similar except the movable part to block flow consists of either a ball or some other shape such as a disc or flapper.

The water control check valve generally consists of a valve body, movable body (flow obstructor), seating or bearing surface/material, and closing mechanism and ancillary components. The standard check valve body is available as a double-disc, wafer, globe, or specialized style body. The valve body is typically cast iron or ductile iron with bronze or stainless steel trim. The closing mechanism is typically a torsion spring that closes the movable body in advance of flow reversal reducing the potential for waterhammer or damaging shock associated with operational valve shut-off. Seating is between the valve disc or plug and the seating material or surface. The valve disc is typically either comprised entirely of metal or some check valve types use a modeled polymer that is reinforced with a metal disc. The seating action is to provide a water-tight seal on either a Buna-N, nylon, metal, or various other types of seating surfaces. Other types of check valves are available with a variety of options, such as closing mechanisms, seating surfaces/materials, and other components; but all provide the same general function.

**Relief and Surge Protection Valves.** – Relief and surge protection valves are designed to prevent damage from water hammer phenomena in a piping system. The relief valve opens when the piping system pressure exceeds the set shut-off pressure of the valve disc. The benefits of a properly design relief valve is that the vale has quick speed of response, excellent flow characteristics, and durability in high pressure applications.

Normally the valve is closed by a compression spring or system of nested springs. During a high-pressure event as the disc opens, the surge pressure rise that caused it to open is dissipated through the open valve orifice. When system pressure drops below the set shut-off pressure, the typical surge relief valve allows for the valve disc to slowly close against the oil or air contained in the cushion chamber and cylinder. Surge relief valves are designed with a smooth flow and minimal obstruction to flow for efficient surge relief.

There are three basic configurations of air valves: air release valves, air/vacuum valves, and combination air valves. Air release valves are sometimes referred to as a “small orifice” valve and continuously release accumulated air during operation of a piping system. Air/vacuum valves are sometimes referred to as “large orifice” valves and are used to exhaust large quantities of air upon start-up and to allow air to re-enter the piping system upon system shutdown or failure. Combination air valves are the mostly commonly used air valve according to Val-matic. They perform the function of an air/vacuum vale (exhaust large quantities of air on start-up, admit air on shut-down) and air release valves (release air continuously during operation).

The main body and cover of a relief valves are typically made from ductile iron with internal components are either ductile or stainless steel. There are some manufacturers
and applications that allow for cast steel or bronze metal components. Relief valves typically contain a disk and diaphragm assembly that forms a sealed chamber below the valve cover, separating operating pressure from line pressure. The diaphragm is typically constructed of nylon reinforced Buna-N rubber and does not seal directly against the valve seat but is fully supported by the valve body and cover. The valve seats from some manufacturers may be either Acrylonitrile-Butadiene (NBR), terpolymer of Ethylene, Propylene and A Diene (EPDM), Nylon Reinforced Buna-N Rubber, or Fluoro Rubber (FKM).

Manufactured surge relief valves are available in sizes for single body valves from 2-inch to 20-inch (0.051 to 0.508 meter) with pressure relief ratings, according to Cal-Val and Val-matic, up to 300 psi (2068 kPa). Air relief valve bodies can be either angle (elbow) or globe pattern style. Y-pattern valve design is not permitted by the noted valve manufacturers.

For more information on surge and air relief valves, refer to the following example manufacturer websites for Val-matic (www.valmatic.com), Cla-Val (www.cla-val.com), and DeZurick (www.dezurik.com). There are also surge suppression and vacuum relief valves which were not covered in this paper.

Mokveld Valves. – The Mokveld Valve is an Axial flow Control Valve. Originally designed for hydro power plants in the early 1900's, Mokveld adopted the principle in 1955, and has been continuously refining it for use in Specialized Water projects, and Oil & Gas Transmission. The valve's unique design offers numerous advantages in High Pressure Drop/Low backpressure installations where Cavitation is a problem:

- Pressure Balanced Piston - All internal hydraulic forces are self-cancelling, making operating thrust independent of the differential pressure across the valve.
- Bubble Tight Shutoff – Mokveld has a patented self-energizing seal that advertises it can achieve repeatable 100% bubble tight shutoff at full rating, utilizing the pressure differential across the valve. The seals retract from the cage wall during normal flows, making them erosion-proof.
- Multiple Cage Trims – Several trim, (cage) styles have been developed, each tested and certified for Cavitation index, (Kcs) CV, and Choked Flow (Fl) at the Delft Hydraulic Laboratory. From "V" port, (low heads) to 3-Stage Multi-Impingement, (capable of breaking up to 5000 feet (1524 m) of head) to custom combinations tailoring stroke vs CV to achieve linear characteristics, even with dramatically changing heads (such as on long pipelines). Mokveld is the only valve that can be tailored specifically for the project's hydraulic requirements.
- Compact Design - Up to three stages of energy dissipation within a single compact body, (eliminating the need for stilling wells or expansion tanks) and allowing discharge directly back into closed conduits.
- Proven Performance - Numerous Waterworks installations breaking up to 1100 psi (to atmosphere) in service over 20 years.
- Sizes 6-inch (0.152 m) to 72-inch (1.829 m)
The following images are a general cutaway, several cage trim types, a detail on the self-energized seals, the pressure balancing, and a photo of an 18-inch-diameter (0.4572 m) valve at the Manitou Springs Hydro-Plant. This valve has been in service since 1995, and breaks 1130 psi to atmosphere.

Figure C-1. Mokveld Valve Cutaway Diagram (Courtesy of Mokveld Valves BV)

Figure C-2. Model RVX Cage Detail (Courtesy of Mokveld Valves BV)
Figure C-3. Model RCX Cage Detail (Courtesy of Mokveld Valves BV)

Figure C-4. Model RMX Cage Detail (Courtesy of Mokveld Valves BV)
Design concerns with the Mokveld valve include plugging of the cage sleeve and may require routine maintenance.