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TECHNICAL REPORT REMR-OM-14

REMR MANAGEMENT SYSTEMS–NAVIGATION STRUCTURES

CONDITION RATING PROCEDURES FOR TAINTER AND BUTTERFLY VALVES

by

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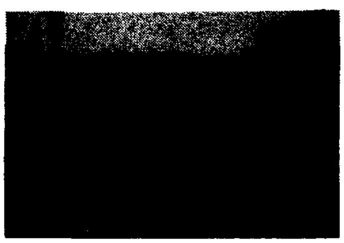

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GT	Geotechnical	EI	Environmental Impacts
HY	Hydraulics	OM	Operations Management
CO	Coastal		

COVER PHOTOS:

TOP - Tainter valve at McAlpine Lock in Louisville District.

BOTTOM - Typical butterfly valve used at locks in Pittsburgh District.

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13. ABSTRACT (Maximum 200 words)

This report presents the development of condition rating procedures for tainter and butterfly filling and emptying valves for navigation lock structures. Several site visits and field investigations were conducted, experts from the U.S. Army Corps of Engineers were asked to rate the valves, and the results were compared to a preliminary version of the rating system. Modifications were made to reflect the experts' opinions more accurately. In the following document, a general description of the current inspection and rating system is given. This includes the definition of a condition index and a description of valve distresses. A detailed description of the inspection follows. Once the inspection data is gathered, condition indexes for valves can be computed.

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PREFACE

The study reported herein was authorized by Headquarters, US Army Corps of Engineers (HQUSACE), as part of the Operations Management problem area of the Repair, Evaluation, Maintenance, and Rehabilitation (REMR) Research Program. The work was performed under Civil Works Research Work Unit 32280, "Development of Uniform Evaluation for Procedures/Condition Index for Deteriorated Structures and Equipment," for which Dr. Anthony M. Kao is the Principal Investigator. Mr. James E. Crews (CECW-O) is the REMR Technical Monitor for this work.

Mr. William N. Rushing (CERD-C) is the REMR Coordinator at the Directorate of Research and Development, HQUSACE; Mr. James Crews and Dr. Tony C. Liu (CECW-EG) serve as the REMR Overview Committee; Mr. William F. McCleese, US Army Engineer Waterways Experiment Station, is the REMR Program Manager; Dr. Kao is the Problem Area Leader for the Operations Management problem area.

This study was performed by the Department of Civil and Construction Engineering, Iowa State University, under contract to the US Army Construction Engineering Research Laboratories (USACERL). Principal Investigators for Iowa State University were Lowell Greimann, James Stecker, and Joel Veenstra. The study was conducted under the general supervision of Dr. Paul A. Howdyshell, Chief of the Engineering and Materials Division (FM), Infrastructure Laboratory (FL), USACERL. The USACERL technical editor was Gloria J. Wienke, Information Management Office.

LTC David J. Rehbein was Commander of USACERL and Dr. L.R. Shaffer was Director.

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CONVERSION FACTORS, NON-SI TO SI (METRIC) UNITS OF MEASUREMENT

Non-SI units of measurement used in this report can be converted to SI (metric) units as follows:

Multiply	By	To Obtain
feet	0.3048	meters
inches	0.0254	meters
square ft	0.0929	square meters
square inches	6.4516	square centimeters

REMR MAINTENANCE SYSTEMS-NAVIGATION STRUCTURES
CONDITION RATING PROCEDURES
FOR TAINTER AND BUTTERFLY VALVES

PART I: INTRODUCTION

Background

1. The US Army Corps of Engineers has been involved in the design and construction of a large number of civilian projects in the past 100 years. Because many of these structures are nearing or have exceeded their design lives and fewer opportunities for project expansion exist, the Corps has been shifting its emphasis. Fewer new structures are currently being built and the maintenance of existing facilities has become increasingly more important and expensive. Addressing its changing role, the Corps has instituted a Repair, Evaluation, Maintenance, and Rehabilitation (REMR) program for civil works structures.

2. As a part of this program, the project team at Iowa State University (ISU) has undertaken a research effort focusing on the inspection and rating of the valve structure used in the filling and emptying systems of navigation locks. Before proper maintenance can be performed, a consistent means of monitoring the condition of the structure must be established to identify areas of concern. To identify where maintenance is necessary and to ensure a continuous working life for the structure, it is necessary to implement a uniform inspection program. Such a program must be capable of detecting problems at an early stage. This allows the engineers time to analyze inspection information and suggest remedial action, if required.

3. Valves are critical operating components of a lock and dam facility. At many lock and dam locations there is no auxiliary lock. Therefore, if the valve structure and the operating components fail to function or function improperly, lock operation can be severely affected. In addition, if a single lock is inoperable, navigation along the entire river may be delayed, resulting in large user costs.

Objective

4. The objective of this work is to develop a uniform inspection and rating procedure to describe the current condition of valve structures.

Mode of Technology Transfer

5. It is recommended that the inspection procedures developed in this study for tainter and butterfly valves be incorporated into Engineer Regulation (ER) 1110-2-100, "Periodic Inspection and Continuing Evaluation of Completed Civil Works Structures."

Overview

6. The concepts and ideas presented here for the inspection and rating of valves rely heavily on work in similar projects for steel sheet pile structures (Greimann and Stecker, 1989, 1990), miter lock gates (Greimann et al., 1990) and sector gates (Greimann et al., 1991). During that earlier work, basic ideas such as condition indexes, safety and serviceability, quantification of distresses by field measurements, limiting values of distresses, and others began to evolve. As these concepts were applied to valve structures, several modifications and new ideas have developed.

7. During the course of this project, the project team at ISU held many meetings with Corps personnel and conducted site visits and field investigations at several lock and dam facilities. At these meetings and site visits, several basic considerations for valves were identified. Corps experts conveyed their opinions on the critical components of valve operation and repair. They suggested means of quantifying these components and relating them to the overall condition of the valves. The project team formulated the experts' comments into an inspection procedure and a tentative set of rating rules.

Field Inspection

8. The inspection and rating procedure is illustrated schematically in Figure 1. The entire process is based on a field inspection of the valve structure. The inspection procedure is a tool used to gain consistent information for the rating of many structures. To obtain the set of data that describes the structure, an inspection form was developed. During the inspection, current physical attributes of the systems are obtained. Data, such as the location of the gate, inspection history, maintenance history, and general component information, are recorded on the first two pages of the inspection form. Additional pages provide space for several field measurements such as trunnion assembly wear, anchorage deterioration, and corrosion. These measurements are used directly to rate the condition of the gate.

9. In the next phase of research, the information collected on the inspection form is entered into a data file on a microcomputer, which performs all the calculations necessary to rate the valve.

Condition Index

10. The rating of the valve is described in terms of a condition index (CI), which is a numerical measure of the current state of a structure. Part of the goal of this project is to define a condition index that uniformly and consistently describes and ranks the condition of valve structures. The condition index is primarily a planning tool, with the index value serving as an indicator of the general condition level of the structure. The index is intended to focus management attention on those structures most likely to warrant immediate repair or further evaluation. In addition, the CI values can be used to monitor change in general condition over time and can serve as an approximate comparison of the condition of different structures.

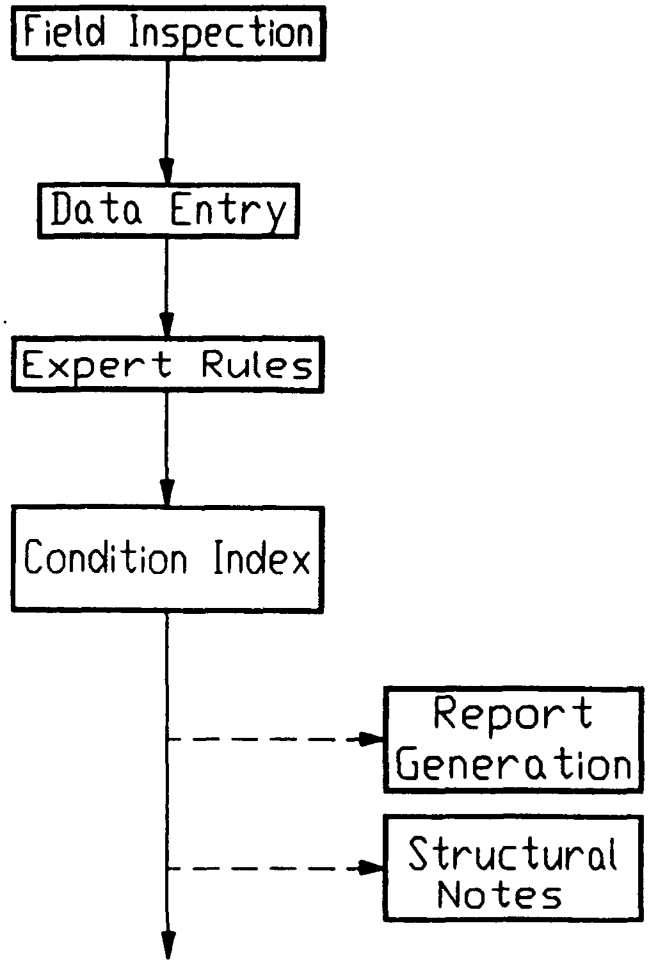

Figure 1. Inspection and rating procedure

11. In previous work by the ISU project team, a common definition of condition index for the REMR work was established (Table 1). The REMR Condition Index is a numbered scale, from a low of 0 to a high of 100. The numbers indicate the relative need to perform REMR work because of deteriorating characteristics of the structure. For management purposes, the condition index scale is calibrated to group structures into three basic categories or zones, as listed in the table.

Valve Description

12. Valves are used inside the culverts of the filling and emptying systems of lock structures (Figure 2). Two valves are necessary in each longitudinal culvert. A filling valve is located between the upper pool intake and the chamber intake ports. An emptying valve is located between the chamber outlet ports and the lower pool discharge.

13. Many different types of valve structures have been used in the past. In 1930 the American Society of Civil Engineers published a manual on lock culvert valves that described valves at 12 projects, "all of reasonably recent construction." At these 12 projects, 7 types of valves were used, namely stoney gate, cylindrical, wagon body, butterfly, spool, slide gate, and tainter (US Army Corps of Engineers, 1975). Tainter valves are primarily used in most Corps of Engineers navigation structures today. Butterfly valves were predominantly used in the Corps of Engineers Pittsburgh District (US Army Corps of Engineers, 1982). Therefore the bulk of this research focused on these two types of valves.

Tainter Valve

14. Initially, tainter valves were designed similar to the spillway tainter gates used on dam structures. These valves were oriented with the trunnions downstream of the skin plate causing the convex surface of the skin plate to face the flow and seal along the upstream end of the valve pit (Figure 3). After studies showed that this design could cause air to be pulled into the culvert, a reverse tainter valve design was introduced (US Army Corps of Engineers, 1975). This orientation placed the trunnions upstream of the skin plate with the convex surface of the skin plate facing downstream and sealing against the downstream end of the valve pit (Figure 4). Valves of this general design have been used on most locks constructed by the Corps of Engineers in recent years.

15. A tainter valve is generally anchored to the concrete with an anchor plate and a trunnion bearing bolted to an embedded frame. Because the trunnion assembly of a tainter valve is downstream, the strut arms are in compression (Figure 3). In the case of reverse tainter valves, there are two distinct types of anchorage design. The first and more common design uses a

Table 1

REMR Condition Index Scale

Zone	Condition Index	Condition Description	Recommended Action
1	85 to 100	Excellent: No noticeable defects. Some aging or wear may be visible.	No action is required.
	70 to 84	Very Good: Only minor deterioration or defects are evident.	
2	55 to 69	Good: Some deterioration or defects are evident, but function is not significantly affected.	Economic analysis of repair alternatives to determine appropriate action.
	40 to 54	Fair: Moderate deterioration. Function is still adequate.	
3	25 to 39	Poor: Serious deterioration in at least some portions of the structure. Function is inadequate.	Detailed evaluation is required to determine the need for repair, rehabilitation, or reconstruction. Perform safety inspection.
	10 to 24	Very Poor: Extensive deterioration. Barely functional.	
	0 to 9	Failed: No longer functions. General failure or complete failure of a major structural component.	

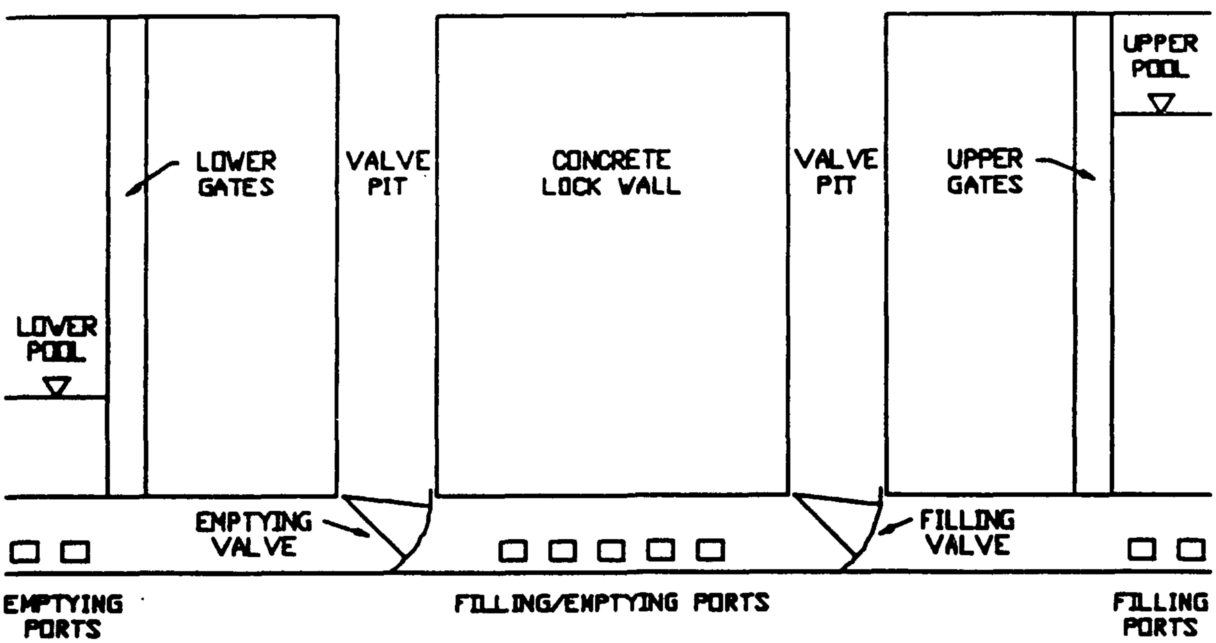

Figure 2. Lock chamber schematic

bearing plate arrangement anchored on a concrete shelf on each side of the culvert (Figure 4). The strut arms are in tension. Anchor bolts are connected to an embedded framework inside the culvert walls. In this design, the anchorage assembly is in compression. The second design, uses U-bolts to anchor the valve to the concrete (Figure 5). The U-bolts are connected to an embedded trunnion girder. This type of design puts the anchorage assembly in tension.

Butterfly Valve

16. In general, butterfly valves are used only on relatively old structures. The Pittsburgh District is one of the few districts with such structures in operation today.

17. Butterfly valves were designed in a variety of sizes and shapes. Some are circular and some are rectangular; some rotate on a horizontal axle and others on a vertical axle. Because the majority of butterfly valves in service today are rectangular shaped with a horizontal axis, research focused on this type.

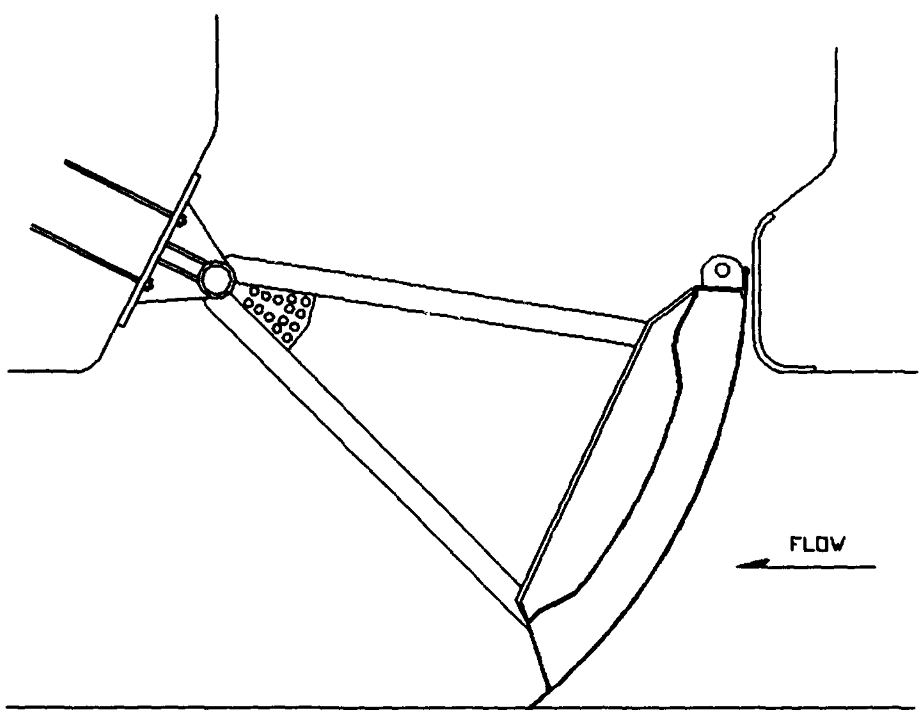

Figure 3. Conventional tainter valve

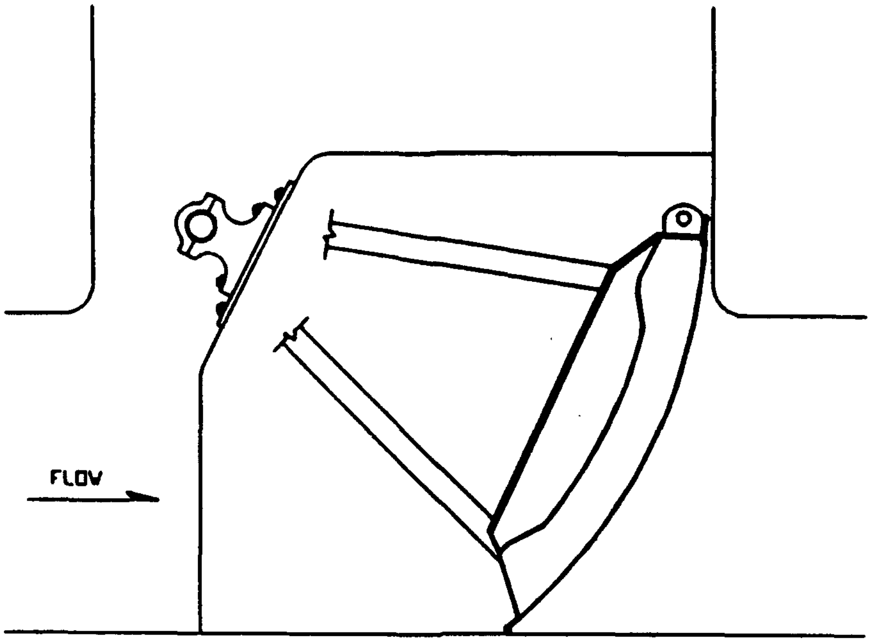

Figure 4. Reverse tainter valve

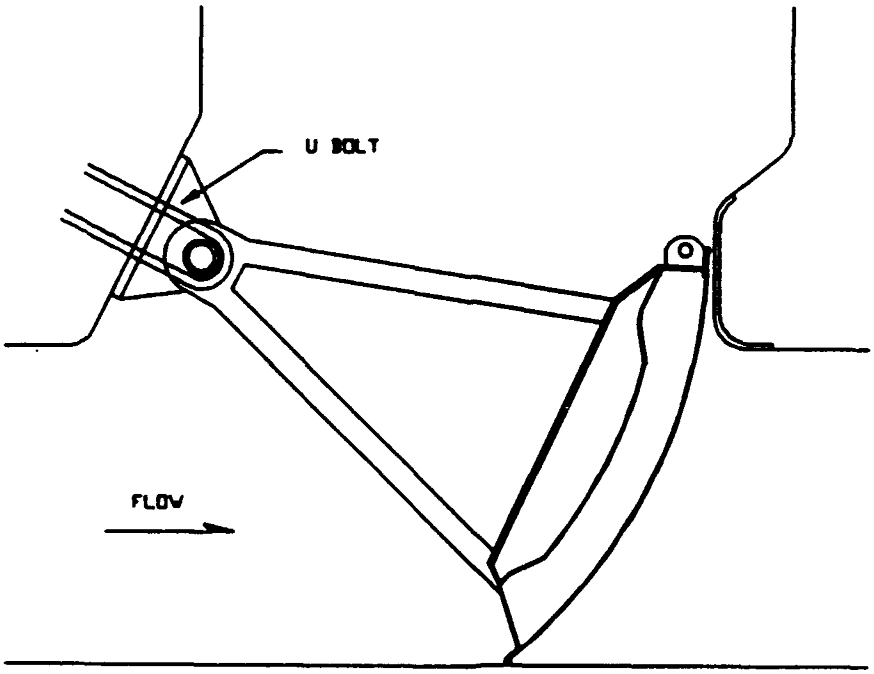

Figure 5. Reverse tainter valve U-bolt arrangement

Valve Component Identification

18. To inspect and rate valve structures, you need to be familiar with the configurations and components; definitions and sketches for these components are presented in the following paragraphs:

Tainter Valve

Skin Plate: A skin plate is welded to the horizontal girders to provide stiffness to the structure (Figure 6). It dams the water and transfers load to the girders.

Horizontal Girders: Horizontal girders span the width of the valve and transfer load from the skin plate to the segmental girders (Figure 6).

Segmental Girders: These girders are positioned on each side of the valve, perpendicular to the horizontal girders. They transfer load from the horizontal girders to the strut arms (Figure 6).

Strut Arms: Strut arms are the steel girders that transfer load from the segmental girders to the trunnion assembly (Figure 6).

Trunnion Assembly: The trunnion assembly consists of a set of components that make up the hinge system of the valve. It transfers load from the strut arms into the embedded anchorage system in the culvert walls. Specific arrangement of components varies, depending on the configuration of the anchorage design (Figures 3, 4, and 5).

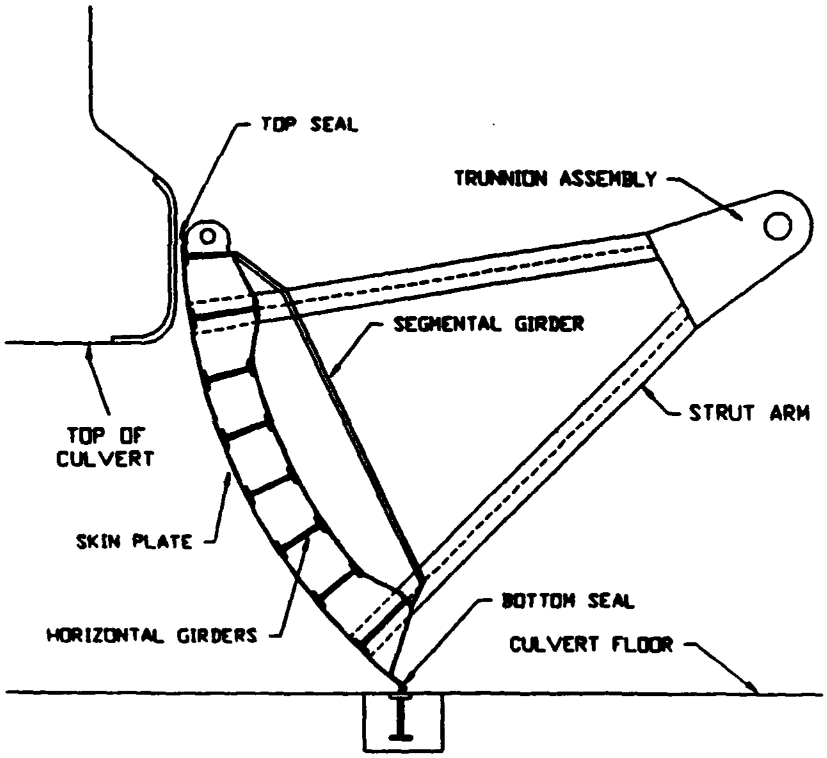

Figure 6. Tainter valve components

Lifting Strut: The lifting strut connects the operating machinery with the valve structure (Figures 7 and 8). It extends down into the valve pit and moves the valve between its open and closed positions.

Lifting Chain or Cable: Sometimes the valve is lifted by a chain or cable rather than a strut (Figure 7). Its function is the same as a lifting strut.

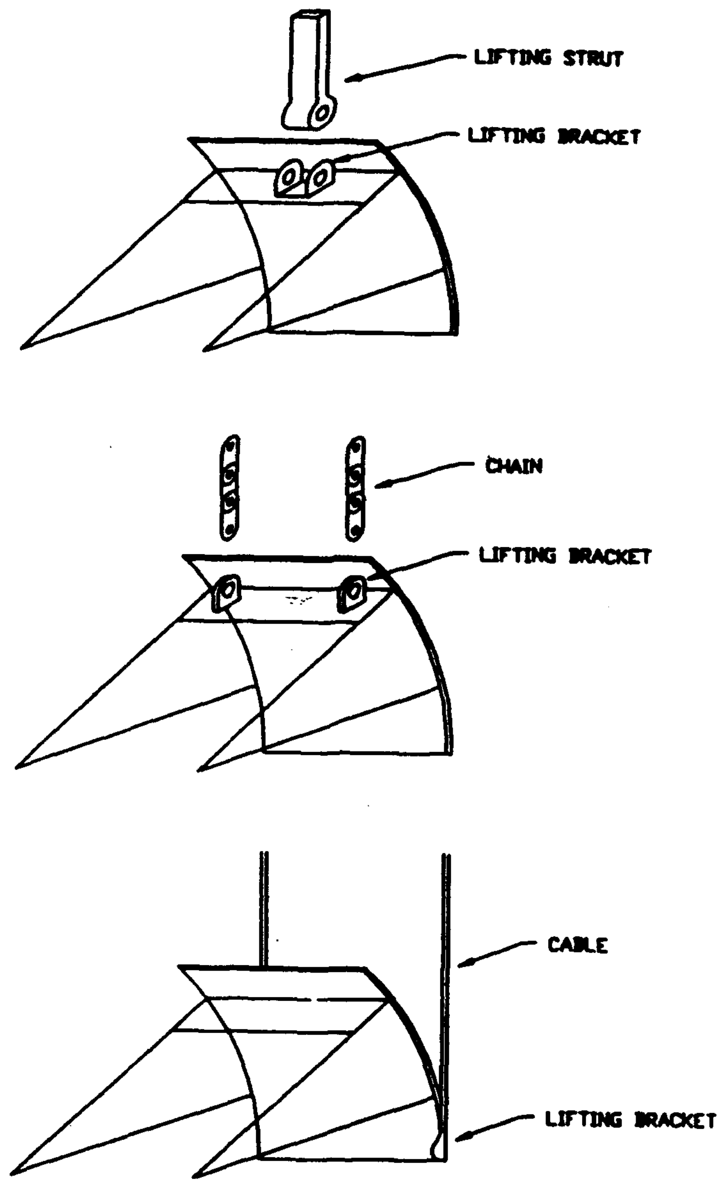

Figure 7. Tainter valve lifting methods

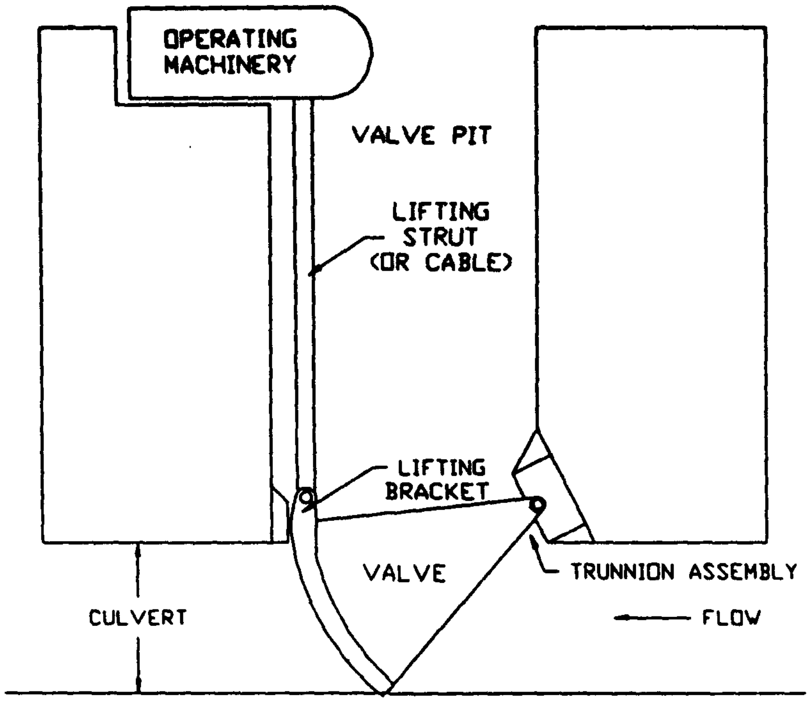

Figure 8. Tainter valve schematic

Lifting Bracket: The lifting bracket is usually located on the top side of the valve and connects the lifting strut to the valve structure (Figure 7). In the case of a cable-lifted valve, the cables connect to the bottom of the valve arch (Figure 7).

Seals: Rubber seals are used on each side and on the top of the valve to prevent leakage around the valve perimeter. The most common type is the "J" seal. Sometimes the bottom seal is metal-to-metal contact without a "J" seal.

Culvert: Culverts are the concrete passages inside the lock monolith which provide the means for filling and emptying the lock chamber (Figures 2 and 8).

<u>Butterfly Valve</u>

Skin Plate: The skin plate, which forms the body of the valve, dams the water and transfers load to the internal framework of the valve (Figure 9).

Stiffeners: Steel "L" sections are welded or riveted across the body of the valve, perpendicular to the axle. They provide stiffness to the skin plate body of the valve (Figure 9).

End Plate: End plates are welded onto the sides of the valve to enclose the ends of the valve and transfer load to the axle (Figure 9).

Seal Plate: Seal plates are attached to the perimeter of the valve to provide a sealing surface (Figure 9). Either rubber seal strips are attached, or the steel-to-steel contact will provide an adequate seal.

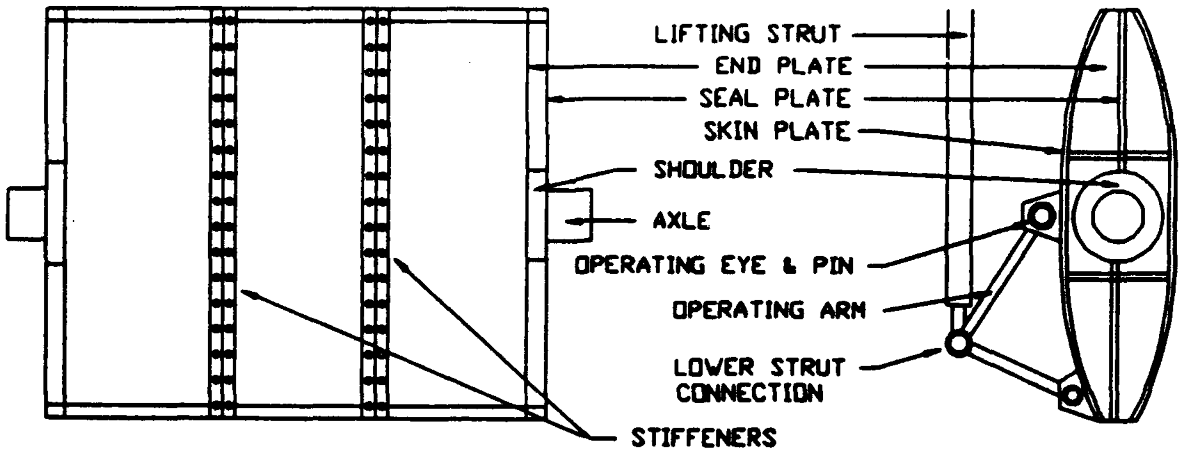

Figure 9. Butterfly valve components

Shoulder: The shoulder is a spacer surrounding the axle that absorbs the lateral thrust and centers the valve in the culvert (Figure 9).

Valve Axle: The valve axle is a cylindrical member spanning the width of the valve (Figure 9). It transfers load from the valve body to the center frame assembly and provides a bearing surface for rotation on each side of the culvert.

Axle Bushing: This is a bronze bushing mounted inside the center frame (Figure 10). It provides a wearing surface for the valve axle and transfers load from the axle to the center frame.

Valve Frames: The valve frame is embedded in the walls of the culvert around the perimeter of the valve (Figures 10). It is comprised of several components that provide a pivot point, perimeter sealing surfaces, and a means of removal for repair. Components include the top and bottom frames, side frames, center frame, center frame bearing block, center frame key, and center frame keeper.

Center Frame: The center frame is an embedded framing on the sides of the culvert (Figure 10). It is bolted to the side frame and is shaped to provide a means of valve removal. It houses the axle bushing and transfers load from the bushing into the side frame.

Center Frame Bearing Block: This slotted bearing block fits in the center frame and provides an upstream bearing surface for the bushing (Figure 10).

Center Frame Key: The center frame key is slotted perpendicular to the bearing block and prevents the bearing block from sliding out of the center frame (Figure 10).

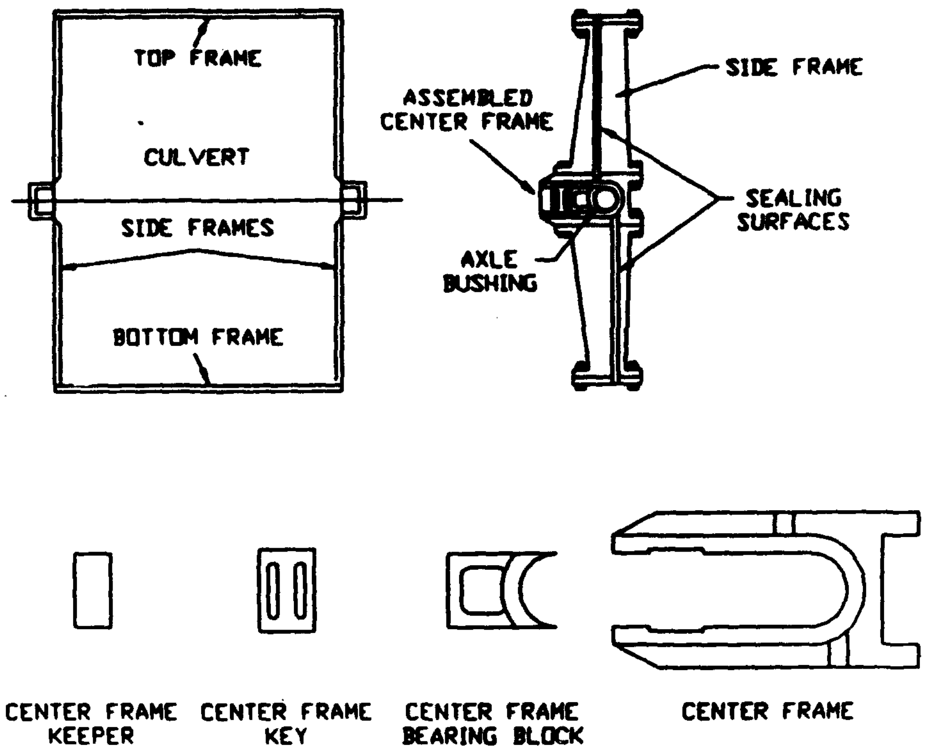

Figure 10. Butterfly valve anchorage assembly

Center Frame Keeper: The keeper is an end block that holds the center frame assembly together by means of screws spanning through the key and into the bearing block (Figure 10).

Lifting Strut: The lifting strut connects the operating machinery with the valve structure (Figure 9). It extends down into the valve pit and moves the valve between its open and closed positions.

Lower Strut Connection: This is the bottom connection point of the strut to the operating arms (Figure 9).

Operating Arms: Operating arms are cast steel members that connect the lifting strut to the body of the valve (Figure 9). There are two sets of arms on each butterfly valve. As the lifting strut is raised or lowered, one set is in tension and the other set in compression, causing the valve to rotate.

Operating Eyes: Cast steel operating eyes are welded onto the stiffeners on the body of the valve (Figure 9). They provide pivot points at which the operating arms are pinned to the valve body.

PART II: FIELD INSPECTION

Inspection Procedure Development

19. Simplicity and adaptability form the basis of the inspection procedure. Conforming to these guidelines, the valve structure inspection program had to be applicable to a wide variety of valve structures and yet relatively straightforward for Corps personnel to learn and implement in the field.

20. For rating systems previously developed by the ISU project team, the field inspection was based on data that was obtainable from the top of the lock gates or lock wall or from a boat in the lock chamber. All data were measured with a tape measure, a level, a ruler, dial gauges, or by subjective observation (poor, average, good, excellent, etc.). This was done to keep the procedure as simple as possible and to keep the lock in an operating mode, while still obtaining quantitative and applicable information to assess the structure. This type of inspection procedure used information gathered without using a diver and without the time, effort, traffic delays, and funds needed to dewater the lock. As meetings and field tests with Corps personnel progressed, it became increasingly clear that the application of these same principles to valve structures posed certain problems.

21. Because a valve structure is completely or partially submerged during operation, it is very difficult to observe problems that arise in its range of motion. In many instances sufficient information cannot be accumulated from indicators and observations on top of the lock wall. Butterfly valves, for example, are completely submerged during all phases of operation, making them impossible to inspect without dewatering the valve pit or conducting an underwater inspection. In light of these findings, the concept of simply gathering inspection data from the lock wall had to be modified. Even though inconsistent with previously developed inspection procedures, the decision was made to incorporate both a dewatered (dry) inspection and a submerged (wet) inspection into the valve inspection procedure.

22. In addition to simplicity, the other goal was to develop a general inspection procedure that was adaptable to many different types of valve structures. Tainter and butterfly valves are the two primary types, for example, but they are structurally very different from each other. Also, within each type of valve there are numerous design configurations. Tainter and reverse tainter valves dam the water on opposite sides of their skin plates, causing different anchorage designs to resist the hydrostatic forces. Butterfly valves can be round or rectangular with either vertical or horizontal axes. To accommodate these structural variations, separate inspection

forms were developed for tainter and butterfly valves. Even though the forms are different, the same distresses are addressed on each form, establishing a consistent procedure for both types.

23. In trying to develop the overall procedure to inspect and evaluate valve structures, two types of inspections were developed: dry and wet.

Dry Inspection

24. A dry inspection requires dewatering of the valve pit. Initially, this seems like the best procedure because most distresses can be evaluated more accurately when dry. In reality, though, the dewatering process is very costly and can slow or even stop lock operation. In addition, the ease in implementing such a procedure regularly varies. Some locations have culvert bulkheads on site that are readily available for use, while some Corps districts maintain a single set of bulkheads that are used at a number of different lock sites. Similarly, some locations have a crane or other hoisting mechanism permanently on site to place the culvert bulkheads, while other locations rely on the availability of a floating derrick crane.

Wet Inspection

25. A wet (or submerged) inspection of a valve uses information from a diver inspection, specific indicators above the waterline, and a measurement projection where necessary.

Diver Inspection: The diver inspection is the primary source of information. A diver can record certain valve distresses without dewatering the valve pit. For example, a diver can feel the condition of seals, check if the lubrication system is functional, and record the corrosion on the valve. Monitoring the action of certain components that are not permanently submerged can also give an indication of behavior underwater. For example, vibration of the unsubmerged portion of the lifting strut could indicate seal leakage around the perimeter of a tainter valve.

Measurement Projection: A measurement projection is an estimated wear value based on historical data. The projected values are used in conjunction with a wet inspection, specifically when a diver cannot gather the needed information. In many instances, even though sufficient information cannot be gained from a wet inspection, it is difficult to justify the time and expense required to perform a dry inspection. In such a case, a projected measurement may be adequate. For example, trunnion bushing wear is difficult to observe during a wet inspection because simple underwater measurement techniques do not exist. During a dry inspection the valve is jacked and dial gauges are used to measure the wear. A similar underwater procedure to load the valve and move the axle relative to the bushing is difficult. For distresses such as wear, measurements projected from historical data can be used in place of physical measurements. For instance, when an old valve is replaced or rehabilitated in the Pittsburgh District, the worn axle and bushing diameters are recorded. In addition, the age of the valve, its number of lockages, and other site-specific conditions are available. With this data, it is possible to chart previous wear and estimate future wear on valves currently in service. The data gathered from this method will be less accurate than from a dry inspection, but it can be useful where dewatering is not feasible.

26. Because there are many types of valve structures and because some districts have the resources to dewater valves more frequently than others, a combination of the different inspection techniques is necessary. As a rule of thumb, though, the quality of the acquired data decreases from a dry inspection to a possible measurement projection. Therefore, the accuracy in assessing the condition of the valve also decreases. Consequently, the condition indexes based on projected measurements carry less weight than those based on actual measurements. Dry inspections of rebuilt valves can be used to establish baseline information for future inspection and ratings.

27. Wet inspections involve risks to divers. Recognized safety procedures should be followed carefully.

Overview of Inspection Procedure

28. The overall inspection procedure is illustrated schematically in Figure 11. Many Corps districts currently follow an annual or biannual dive schedule to inspect valves. Working within this established schedule, without dewatering the valve, a wet inspection is the initial procedure in the evaluation process. The information from a wet inspection is used to calculate an initial condition index. If measurement projections are available, they can be used to supplement the diver's inspection. Consecutive wet inspections are performed until the entire lock is dewatered for maintenance or the initial CI value becomes low enough to warrant a further investigation. Wet inspections are intended to minimize the number of routine dry inspections. To get a more accurate condition assessment, a dry inspection could be required to acquire an updated CI. Where appropriate, this updated value can be extrapolated to similar valve structures considering age, type, number of lockages, and water conditions. Other valves with similar conditions may be dewatered.

Overview of Inspection Form

29. The inspection forms for tainter valves (pp 24 through 39) and butterfly valves (pp 40 through 47) were designed to provide flexibility in documenting a variety of field conditions. The first two pages of either form

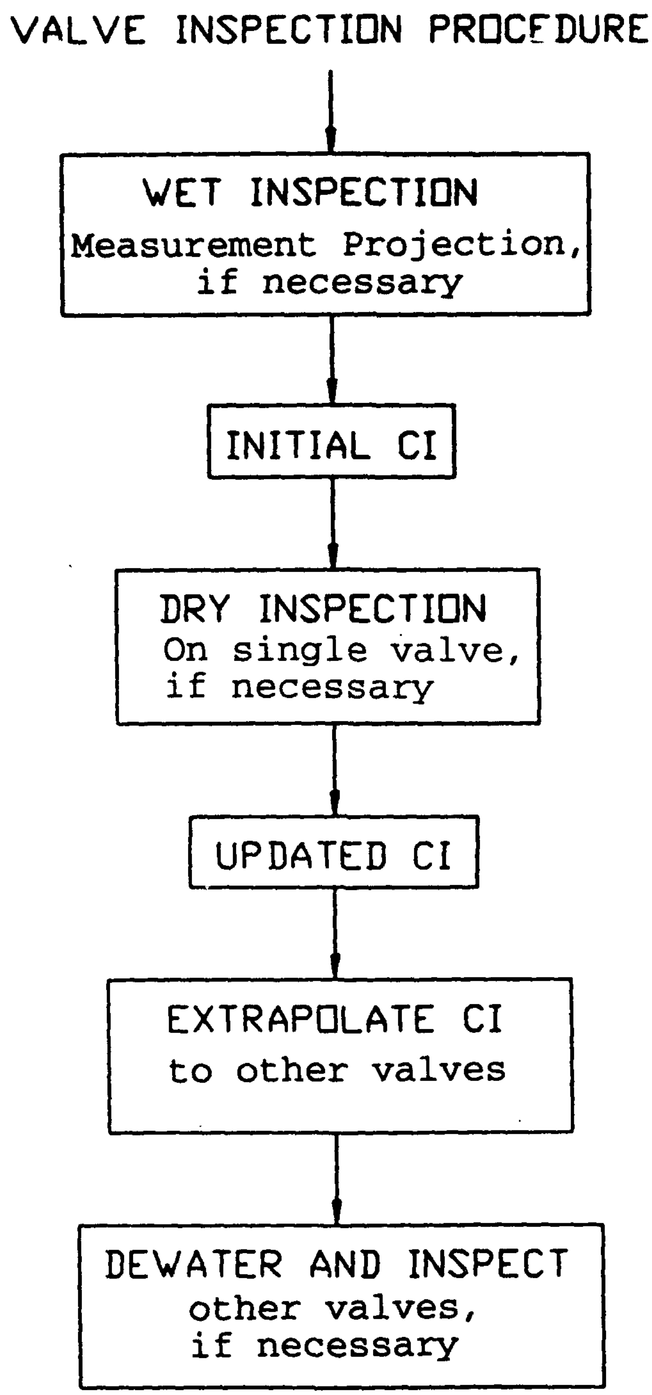

Figure 11. Inspection procedure

address historical information and should be completed before the field inspection. The remaining pages are completed in the field. The following paragraphs briefly outline the inspection form.

Historical Information

30. Historical information related to the valve structure is recorded on pages 1 and 2 of the inspection form. Information includes project reference data to identify and locate the specific structure. Further questions categorize the structure into a particular type and function. Some of the information, such as culvert dimensions, is used to sort through the expert rules in the evaluation process. Historical descriptions of maintenance, modifications, and inspections are recorded on page 2 for reference only.

Field Measurements

31. Pages 3 and 4 of the inspection forms are for recording measurements made in the field. The page numbers are followed by a "D" or "W" to designate a dry or wet inspection. Several measurements concerning anchorage assembly deterioration, trunnion assembly wear, seal condition, cracks, corrosion, lifting bracket bushing wear, and vibrations are requested. These field measurements are used in the expert rules described in Chapter 3 to determine the condition index for the valves.

General Notes

32. The following pages contain the inspection forms for tainter and butterfly valves. The inspection form for butterfly valves was developed primarily for rectangular shaped valves with a horizontal axis. The side-by-side arrangement of the opposing pages displays specific explanations adjacent to the entry on the inspection form.

TAINTER VALVE STRUCTURE INSPECTION

NAME OF CIVIL WORKS PROJECT:

____

____

LOCATION OF CIVIL WORKS PROJECT: (1. Body of water, 2. Nearest town)
1. ____
2. ____

INSPECTION DATE: ______________ INSPECTED BY: ________________

TYPE OF INSPECTION:
1. DRY (Dewatered-Complete pgs. 1,2,3D, 4D)
2. WET (Using diver-Complete pgs. 1,2,3W,4W) (no.)____________

VALVE IDENTIFICATION:
1. FILLING VALVE
2. EMPTYING VALVE (no.)____________

1. LEFT VALVE (Facing downstream)
2. RIGHT VALVE (no.)____________

VALVE ORIENTATION:
1. TAINTER (Head on convex side)
2. REVERSE TAINTER (no.)____________

TYPE OF LIFTING SYSTEM:
1. CHAIN
2. CABLE
3. STRUT (no.)____________

TYPE OF ANCHORAGE:
1. U-BOLT
2. BASE PLATE MOUNTING (no.)____________

TYPE OF ANCHORAGE LOAD
1. TENSION
2. COMPRESSION (no.)____________

TYPE OF TRUNNION BUSHING:
1. EXTERNALLY LUBRICATED
2. GRAPHITE IMPREGNATED
3. OTHER TYPE OF SELF-LUBRICATING (no.)____________

CULVERT WIDTH: (ft)* ________ CULVERT HEIGHT: (ft) ____________

VALVE RADIUS: (ft) __________

NORMAL HEAD OR LIFT: (ft) ____________

WHEN WAS THE VALVE PIT PREVIOUSLY DEWATERED? ________________

* **A table of factors for converting non-SI units of measurement to SI (metric) units is presented on page 5.**

Page 1 Comments: Historical or recordkeeping data.

Complete before the site inspection and verify or change during the site inspection.

Data blanks on page 1 prefaced by (no.)_______ must be recorded as numbers.

Enter the Corps of Engineers Project Title on the NAME lines.

Indicate the BODY OF WATER and NEAREST TOWN.

Indicate the TYPE OF INSPECTION being performed. Enter a 1 for a DRY inspection performed during dewatered conditions and enter a 2 for a WET inspection accomplished primarily by using a diver.

Indicate VALVE IDENTIFICATION, VALVE ORIENTATION, TYPE OF LIFTING SYSTEM, ANCHORAGE, ANCHORAGE LOAD, and TRUNNION BUSHING by entering the appropriate number in the blank following each name. Most trunnion systems are greased by a lubrication line running to the top of the lock wall. Others rely on graphite-impregnated or other kinds of self-lubricating bushings that eliminate the need for grease lines running to the top of the lock wall. Refer to the sections called "Valve Description" and "Valve Component Identification"in Part I for descriptions and illustrative figures if additional information is required.

Enter the HEIGHT and WIDTH of the culvert.

Enter the RADIUS of the tainter valve.

Enter the normal HEAD or LIFT on the dam. This height is important in evaluating how critical seal leakage is.

Dewatering information may be important for reference.

IS THE ORIGINAL VALVE CURRENTLY IN PLACE? (Y/N) ____________

IF SO, WHAT YEAR WAS IT PUT INTO OPERATION? ____________

IF NOT, IDENTIFY CURRENT VALVE HISTORY: ____________________________________

ARE DRAWINGS AVAILABLE FOR THE VALVE IN PLACE? (Y/N) ____________

ARE THE DRAWINGS INCLUDED WITH THIS FILE? (Y/N) ____________

PAST 10 YEAR HISTORY

MAJOR MAINTENANCE, REPAIRS, OR OTHER MODIFICATIONS

	DATE	DESCRIPTION
(1):		
(2):		
(3):		
(4):		

PREVIOUS INSPECTIONS OR STRUCTURAL REVIEWS (attach avail. copies)

	DATE	DESCRIPTION
(1):		
(2):		
(3):		
(4):		

CONDITION OF LIFTING EQUIPMENT: ____________________________________

CONDITION OF GREASING SYSTEM: ____________________________________

OTHER COMMENTS: ____________________________________

Page 2 Comments: Historical or general data.

Complete before the site inspection and verify or change during the site inspection.

Valves are sometimes replaced or removed during rehabilitation. It is important for later reference to record the history of the valve currently in place.

Enter major MAINTENANCE, REPAIRS, OR OTHER MODIFICATIONS performed on the valve within the past 10 years.

Enter PREVIOUS INSPECTION information for reference purposes.

Record the CONDITION OF LIFTING EQUIPMENT and the overall CONDITION OF GREASING SYSTEM.

(Complete for dry only)

ANCHORAGE ASSEMBLY DETERIORATION

	LEFT SIDE		RIGHT SIDE	
CONCRETE CRACKED OR SPALLED?	Y	N	Y	N

	CASTING & ANCHORAGE			
	LEFT SIDE		RIGHT SIDE	
BOLTS/NUTS SIGNIFICANTLY CORRODED?	Y	N	Y	N
ARE THERE ANY LOOSE NUTS?	Y	N	Y	N
BROKEN OR MISSING BOLTS/NUTS?	Y	N	Y	N

	LEFT SIDE (in.)		RIGHT SIDE (in.)	
	CLOSED	OPEN	CLOSED	OPEN
TOP MEASUREMENT	______	______	______	______
BOTTOM MEASUREMENT	______	______	______	______

TRUNNION ASSEMBLY WEAR

	LEFT SIDE			RIGHT SIDE		
ANY PROBLEMS WITH LUBRICATION SYSTEM?	Y	N	NA	Y	N	NA
DOES BUSHING ROTATE?	Y	N		Y	N	
IF YES, IS BUSHING SEIZED TO PIN?	Y	N		Y	N	

LEFT SIDE	INITIAL (in.)	JACKED DS (in.)	RELEASED (in.)	JACKED US (in.)
HOR.	______	______	______	______
VER.	______	______	______	______
RIGHT SIDE				
HOR.	______	______	______	______
VER.	______	______	______	______

SEAL CONDITION

HOW MANY (IF ANY) SEAL BOLTS ARE MISSING? ______
RECORD LOCATION AND LENGTH OF DAMAGED (D) OR MISSINGS (M) SECTIONS

	COND'N--D,M	LOC'N--T,L,R	LENGTH (in.)	DIST. FROM TOP OR LEFT (ft)
(1):	______	______	______	______
(2):	______	______	______	______
(3):	______	______	______	______
(4):	______	______	______	______
(5):	______	______	______	______

CRACKING

COMPONENT: SKIN (S), STRUT ARM & BRACING (A), SKIN FRAMING (F), SEGMENTAL GIRDER (G)

	COMPONENT	LENGTH (in.)	LOCATION
(1):	______	______	______
(2):	______	______	______
(3):	______	______	______
(4):	______	______	______
(5):	______	______	______

Page 3D Comments: Field data.
Complete at site inspection of a dewatered valve pit.

ANCHORAGE ASSEMBLY DETERIORATION: If anchorage movement becomes significant, it can be detected by visually examining the concrete interface for a line where the corrosive buildup is broken. Indicate the presence of excessively cracked or spalled concrete at the interface around the anchorage connections. Excessive concrete spalling may indicate a displacement occurred at this location at some time and may or may not show up in the current inspection. Small hairline cracks, probably caused by thermal expansion or contraction of the concrete, should be ignored in this analysis. Indicate if the anchor or casting bolts and nuts are significantly corroded. Significant corrosion refers to an approximate 10 percent volume reduction. Indicate if anchor and casting nuts are tightened properly. This is done with a torque wrench or by visual inspection for signs of movement between the bolted components during operation. Indicate if there are any broken or missing anchor or casting bolts and nuts. Measurements of relative movement between the concrete and steel are taken on the top and bottom of each anchorage, with the valve in two positions: (1) open (2) and closed. Measurements are made with a dial gauge attached to the steel and bearing on the adjacent concrete (Figure 12). Displacements should be recorded to 0.001 in.

TRUNNION ASSEMBLY WEAR: Indicate if the lubrication system is functional. If a unique situation exists, such as a nonlubricated trunnion, circle NA. Indicate if the bushing rotates. If it does, indicate if the bushing is completely seized to the trunnion pin by monitoring the bushing as the valve is rotated through a full range of motion. Take wear measurements in horizontal and vertical directions, using dial gauges that monitor total displacement between the casting and the trunnion pin (Figure 13). First rotate the valve so the upper strut arm is approximately horizontal (Figure 14). Record measurements with the valve in four jacked positions: (1) initial position before jacking, (2) jacked downstream, (3) jack released, (4) and jacked upstream. Before the gate is jacked in either direction, take an initial baseline reading. Then place a jack between the upstream wall of the valve pit and the trunnion girder (Figure 14), approximately in line with the horizontal strut arm. Jack the valve downstream and take a second set of readings. Release the jack and a take a third set of measurements. The jack can then be placed between the downstream wall of the valve pit and the downstream skin (Figure 15). The valve is jacked upstream and the final set of horizontal and vertical measurements is recorded.

SEAL CONDITION: Record the number of missing seal bolts. This number is not used in the CI calculation, but is used for reference. Record any damaged or missing sections of seal and record the location as, top (T), left (L), or right side (R). A section of seal is considered damaged if it is cracked, ripped, or improperly attached. Missing sections refer to complete sections broken off because of debris, age, or other causes. Also record the length and location of the damaged or missing section. Measure the length with a ruler and indicate the location in reference to the top or left side of the valve.

CRACKS: The presence of cracks on any component is usually not tolerated. Use a ruler or tape measure to determine the location and length of skin plate, strut arm and bracing, skin framing, and segmental girder cracks. The location of the crack should be adequately described for repair purposes and future comparisons. For example, note if the crack occurs in the connection or the main member.

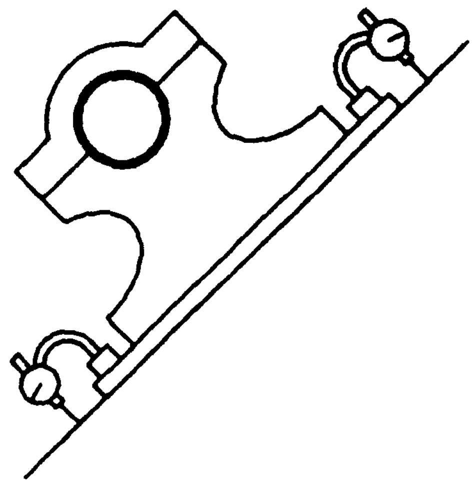

Figure 12. Anchorage movement measurement

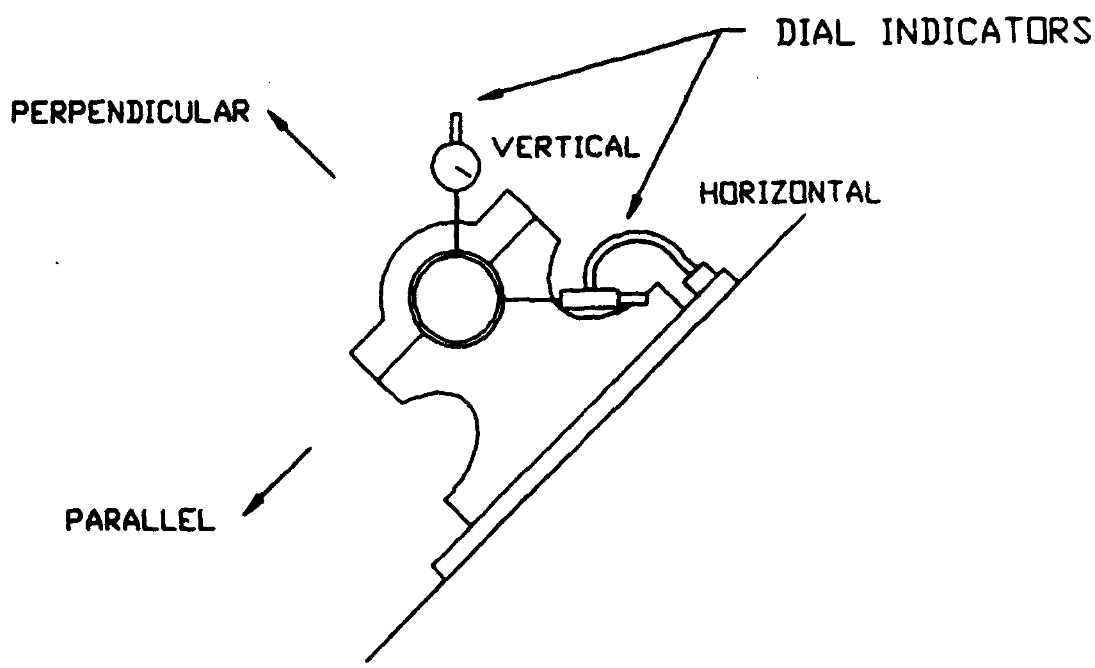

Figure 13. Trunnion assembly wear measurement

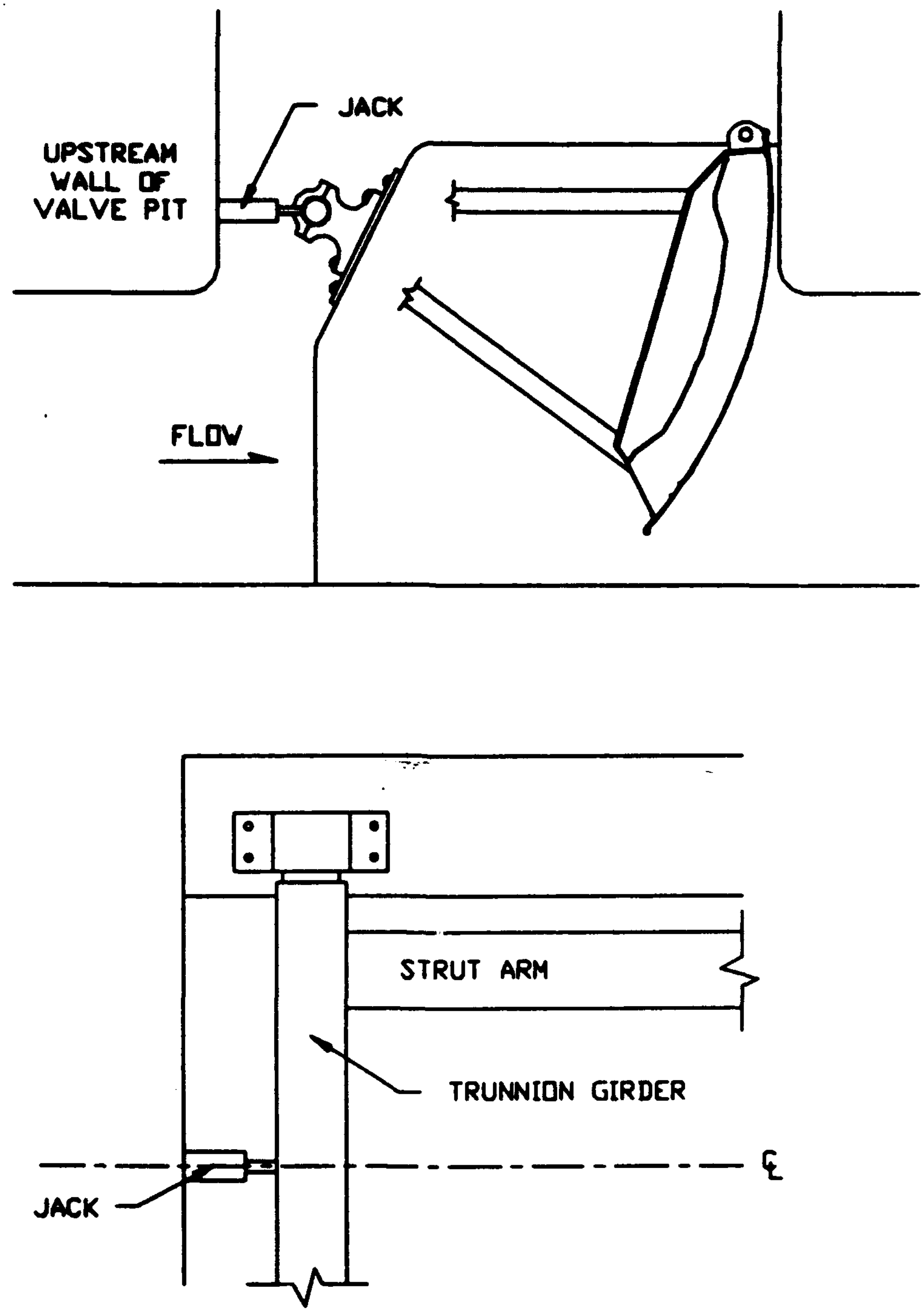

Figure 14. Trunnion assembly jacking locations

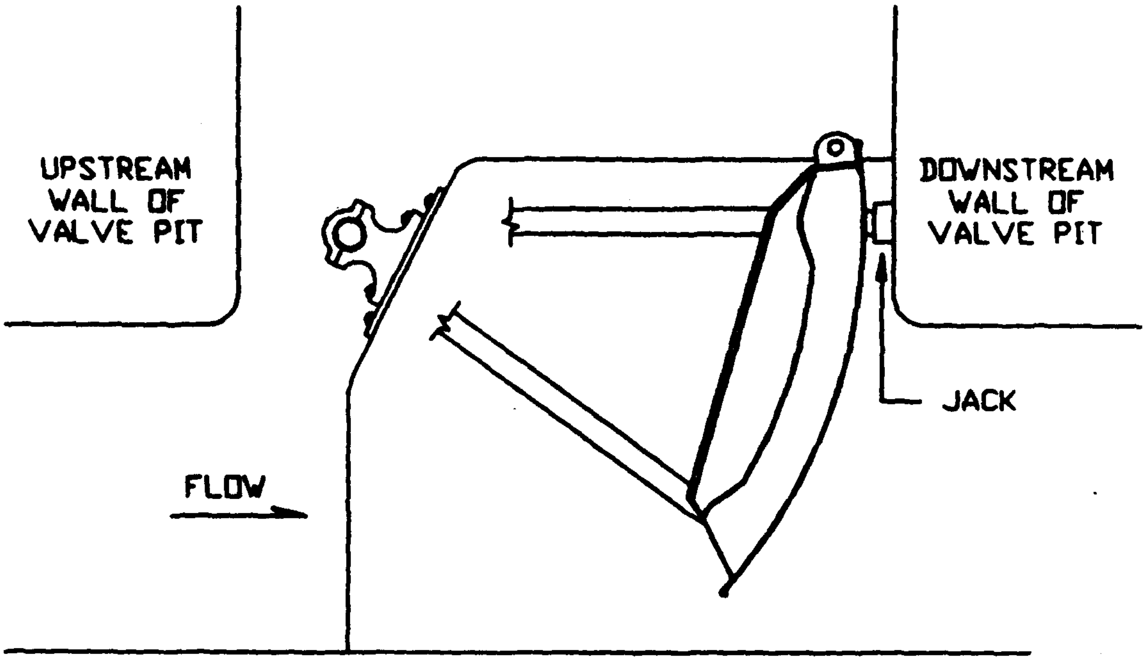

Figure 15. Skin plate jacking location

(Complete for dry only)

CORROSION

	P OR N	SECT THICK	MAX DEPTH	AVG DEPTH	%AREA OR NO. PITS	AVG DIA
US SKIN	____	____	____	____	____	____
DS SKIN	____	____	____	____	____	____
STRUT ARM & BRACKET	____	____	____	____	____	____
SKIN FRAMING	____	____	____	____	____	____
SEGMENTAL GIRDER	____	____	____	____	____	____
SEAL'G SURFACE STEEL	____	____	____	____	____	____

CAVITATION/EROSION/ABRASION

IS CAVITATION PRESENT ON THE DS SKIN? Y N

IF YES, WHAT IS THE MAXIMUM PITTING DEPTH (in.)? ____________

LIFTING BRACKET BUSHING WEAR

LEFT OR CENTER (in.): CLOSED__________ JUST LIFTED__________

RIGHT (in.): CLOSED__________ JUST LIFTED__________

Page 4D Comments: Field data.

Complete at site inspection of a dewatered valve.

CORROSION: For each component, first indicate if the data will be entered by counting the number of pits, N, or by estimating the percentage, P, of the area affected. Estimate or check drawings for the original section thickness. Record the maximum pitting depth. This entry is not used in the CI calculation, but is for reference only. Next, select an area of 1 square foot of corrosion on each component. This area should characterize the maximum density of average depth corrosion. Record the average pitting depth for the area. For the next data column, record either the percentage of the pitted area or count the actual number of representative pits. In the last column, if the data was entered by counting the number of pits, record the average diameter of the representative pits. In some cases, when the percentage area method is used and the deterioration is uniform, the percentage of area affected is 100 percent and the average pitting depth is the average thickness reduction.

CAVITATION/EROSION/ABRASION: Indicate if cavitation deterioration is present on the downstream skin especially near the lip of the valve. If so, record the maximum pitting depth.

LIFTING BRACKET BUSHING WEAR: The lifting bracket bushing wear can be measured in two different ways. A dial gauge or ruler can be used to measure the relative movement as the valve is initially lifted, or a feeler gauge can be used to measure the gap between the pin and bushing. If using a ruler or dial gauge, begin with the valve tightly closed and record an initial reference value. Then lift the valve just off the floor and take a second reading. If there are two pickup points, as with a cable- or chain-lifted valve, enter LEFT and RIGHT measurements. For single-point pickups, record entries in the CENTER blanks. If feeler gauges are used, measure the gap at four locations; top, bottom, and each side. Enter a zero for the CLOSED reading and enter the maximum feeler gauge reading in the JUST LIFTED blank.

(Complete for wet only)

OPENING AND CLOSING OF THE VALVE

		% CLOSED
IRREGULAR VIBRATION?	Y	N________
IRREGULAR NOISE?	Y	N________
DOES THE VALVE JUMP?	Y	N________

ANCHORAGE ASSEMBLY DETERIORATION

	LEFT SIDE		RIGHT SIDE	
CONCRETE CRACKED OR SPALLED?	Y	N	Y	N

	CASTING & ANCHORAGE			
	LEFT SIDE		RIGHT SIDE	
BOLTS/NUTS SIGNIFICANTLY CORRODED?	Y	N	Y	N
ARE THERE ANY LOOSE NUTS?	Y	N	Y	N
BROKEN OR MISSING BOLTS/NUTS?	Y	N	Y	N

TRUNNION ASSEMBLY WEAR

	LEFT SIDE			RIGHT SIDE		
ANY PROBLEMS WITH LUBRICATION SYSTEM?	Y	N	NA	Y	N	NA
DOES BUSHING ROTATE?	Y	N		Y	N	
IF YES, IS BUSHING SEIZED TO PIN?	Y	N		Y	N	
IS IT POSSIBLE TO CHECK WEAR WITH FEELER GAUGES?				Y	N	

IF YES, FILL OUT FOLLOWING TABLE:

	TOP (in.)	BOTTOM (in.)	US (in.)	DS (in.)
LEFT SIDE	________	________	________	________
RIGHT SIDE	________	________	________	________

IF NO, ESTIMATE WEAR FROM MEASUREMENT PROJECTION:

	PIN (in.)	BUSHING (in.)
MAXIMUM WEAR	________	________

SEAL CONDITION

HOW MANY (IF ANY) SEAL BOLTS ARE MISSING? ____________

RECORD LOCATION AND LENGTH OF DAMAGED (D) OR MISSINGS (M) SECTIONS

	COND'N--D,M	LOC'N--T,L,R	LENGTH (in.)	DIST. FROM TOP OR LEFT (ft)
(1):	________	________	________	________
(2):	________	________	________	________
(3):	________	________	________	________
(4):	________	________	________	________
(5):	________	________	________	________

Page 3W Comments: Field data.

Complete at site inspection.

OPENING AND CLOSING OF THE VALVE: Observation of any portion of the unsubmerged valve or lifting equipment during operation is often a good indicator of problems. Indicate by circling the proper answer whether or not the valve or its lifting equipment exhibits any unusual vibration, noise, or jumping. Also record the approximate position where these problems occur.

ANCHORAGE ASSEMBLY DETERIORATION: Indicate the presence of excessive cracked or spalled concrete at the interface around the anchorage connections. Indicate whether the anchor or casting bolts and nuts are significantly corroded. Significant corrosion refers to an approximate 10 percent volume reduction. Indicate whether or not the anchor and casting nuts are tightened properly. This is done with a torque wrench or by visual inspection for signs of movement between the bolted components during operation. Indicate if there are any broken or missing anchor or casting bolts and nuts.

TRUNNION ASSEMBLY WEAR: Indicate whether the lubrication system is functional. If a unique situation exists, such as a nonlubricated trunnion, NA can be circled. Indicate whether the bushing rotates. If it does, indicate whether the bushing is completely seized to the trunnion pin. This is done by monitoring the bushing as the valve is rotated through a full range of motion. If possible, wear measurements are taken on each hinge assembly between the bushing and the pin using feeler gauges. With the valve in a stationary position, take readings in four different locations: (1) top, (2) bottom, (3) upstream side, (4) and downstream side. If this measurement cannot be made, refer to Appendix A for measurement projection information. From the plots of maximum pin and bushing wear, approximate measurements can be selected, depending on the number of lockages for the valve.

SEAL CONDITION: Record the number of missing seal bolts. This number is not used in the CI calculation, but is used for reference. Record any damaged (D) or missing (M) sections of seal and record the location as, top (T), left (L), or right side (R). A section of seal is considered damaged if it is cracked, ripped, or improperly attached. Missing sections refer to complete sections broken off because of debris, age, or other causes. Also, the length and location of each entry is recorded. The length is measured with a ruler and the location is in reference to the top or left side of the valve.

U.S. ARMY CORPS OF ENGINEERS **PAGE 4W**

TAINTER VALVE STRUCTURE INSPECTION (Complete for wet only)

CORROSION

	P OR N	SECT THICK	MAX DEPTH	AVG DEPTH	%AREA OR NO. PITS	AVG DIA
US SKIN	____	____	____	____	____	____
DS SKIN	____	____	____	____	____	____
STRUT ARM & BRACKET	____	____	____	____	____	____
SKIN FRAMING	____	____	____	____	____	____
SEGMENTAL GIRDER	____	____	____	____	____	____
SEAL'G SURFACE STEEL	____	____	____	____	____	____

CAVITATION/EROSION/ABRASION

IS CAVITATION PRESENT ON THE DS SKIN? Y N

IF YES, WHAT IS THE MAX PITTING DEPTH (in.)? ____________

LIFTING BRACKET BUSHING WEAR

IS THERE EVIDENCE OF WEAR AT PICK UP POINT OF VALVE? Y N

IF YES, APPROXIMATE MOVEMENT (in.)? LEFT OR CENTER: 1/16 1/8 1/4
RIGHT: 1/16 1/8 1/4

Page 4W Comments: Field data.

CORROSION: For each component listed, first indicate if the data will be entered by counting the number of pits, N, or by estimating the percentage, P, of the area affected. Estimate or check drawings for the original section thickness. Record the maximum pitting depth. This entry is not used in the CI calculation, but is for reference only. Next, select an area of 1 square foot of corrosion on each component. This area should characterize the maximum density of average depth corrosion. Record the average pitting depth for each area. For the next data column, record either the percentage of the pitted area or count the actual number of representative pits. In the last column, if the data was entered by counting the number of pits, record the average diameter of the representative pits. In some cases, when the percentage area method is used and the deterioration is uniform, the percentage of area affected is 100 percent and the average pitting depth is the average thickness reduction.

CAVITATION/EROSION/ABRASION: Indicate if cavitation deterioration is present on the downstream skin of the valve. If so, record the maximum pitting depth.

LIFTING BRACKET BUSHING WEAR: Indicate if there is any evidence of wear at the pickup point. If yes, the simplest procedure to measure the wear is to use feeler gauges. Measure the gap on the top, bottom, and on both sides of the connection and circle the value closest to the maximum measurement. If feeler gauges cannot be used, an alternative method may be possible. With a diver watching or feeling the pickup point connection, engage the lifting equipment enough to remove the compression from the lifting strut spring and lift the valve slightly. Indicate if there is any evidence of wear and if so, estimate how much by circling the appropriate value. For single point pickups, circle the appropriate entry behind the CENTER prompt. If there are two pickup points, as with a chain or cable lifted valve, enter LEFT and RIGHT measurements.

U.S. ARMY CORPS OF ENGINEERS
BUTTERFLY VALVE STRUCTURE INSPECTION

NAME OF CIVIL WORKS PROJECT:

____

____

____

LOCATION OF CIVIL WORKS PROJECT: (1. Body of Water and 2. Nearest Town)

1. ____

2. ____

INSPECTION DATE: ______________ INSPECTED BY: ____________________

TYPE OF INSPECTION:
1. DRY (Dewatered-Complete pgs. 1, 2, 3D)
2. WET (Using a diver-Complete pgs. 1, 2, and 3W) (no.)__________

VALVE IDENTIFICATION:
1. FILLING VALVE
2. EMPTYING VALVE (no.)__________

1. LEFT VALVE (Facing downstream)
2. RIGHT VALVE (no.)__________

TYPE OF TRUNNION BUSHING:
1. EXTERNALLY LUBRICATED
2. NONLUBRICATED BRONZE
3. NONLUBRICATED MICARTA (no.)__________

CULVERT WIDTH: (ft) ____________________

CULVERT HEIGHT: (ft) ____________________

NORMAL HEAD OR LIFT: (ft) ____________________

WHEN WAS THE VALVE PIT LAST DEWATERED? ____________________

Page 1 Comments: Historical or recordkeeping data.

Complete before the site inspection and verify or change during the site inspection.

Data blanks on page 1 prefaced by (no.)_______ must be recorded as numbers.

Enter the Corps of Engineers Project Title on the NAME blanks.

Indicate the BODY OF WATER and NEAREST TOWN.

Indicate the TYPE OF INSPECTION being performed. Enter a 1 for a DRY inspection performed during dewatered conditions and enter a 2 for a WET inspection accomplished primarily by using a diver.

Indicate VALVE IDENTIFICATION and TYPE OF TRUNNION BUSHING by entering the appropriate number in the blank following each name. Some butterfly axle assemblies are externally lubricated, but most are nonlubricated. In some cases, micarta bushings have been used in place of bronze bushings, resulting in a decrease in the total wear experienced in the nonlubricated systems.

Enter the HEIGHT and WIDTH of the culvert.

Enter the normal HEAD or LIFT on the dam.

Dewatering information may be important for reference.

IS THE ORIGINAL VALVE CURRENTLY IN PLACE? (Y/N) ____________

IF SO, WHAT YEAR WAS IT PUT INTO OPERATION? ____________

IF NOT, IDENTIFY CURRENT VALVE HISTORY: ____________

ARE DRAWINGS AVAILABLE FOR THE VALVE IN PLACE? (Y/N) ____________

ARE THE DRAWINGS INCLUDED WITH THIS FILE? (Y/N) ____________

PAST 10 YEAR HISTORY

MAJOR MAINTENANCE, REPAIRS, OR OTHER MODIFICATIONS

	DATE	DESCRIPTION
(1):		
(2):		
(3):		
(4):		

PREVIOUS INSPECTIONS OR STRUCTURAL REVIEWS (attach avail. copies)

	DATE	DESCRIPTION
(1):		
(2):		
(3):		
(4):		

CONDITION OF LIFTING EQUIPMENT: ____________

OTHER COMMENTS: ____________

Page 2 Comments: Historical or general data.

Complete before the site inspection and verify or change during the site inspection.

Valves are sometimes replaced or removed during rehabilitation. It is important for later reference to record the history of the valve currently in place.

Enter major MAINTENANCE, REPAIRS, OR OTHER MODIFICATIONS performed on the valve in the past 10 years.

Enter PREVIOUS INSPECTION information for reference purposes.

Record the CONDITION OF LIFTING EQUIPMENT.

(Complete for dry only)

AXLE ASSEMBLY WEAR

	LEFT SIDE		RIGHT SIDE	
DOES BUSHING ROTATE?	Y	N	Y	N
IF YES, IS BUSHING SEIZED TO AXLE?	Y	N	Y	N
IS THERE EVIDENCE OF DRAGGING?	Y	N	Y	N

MAX SPRING COMPRESSION ______________ % CLOSED __________________
DESIGN SPECIFIED SPRING COMPRESSION ____________________

	INITIAL (in)	JACKED DS (in)	RELEASED (in)	JACKED US (in)
LEFT SIDE				
VERT				
HOR				
RIGHT SIDE				
VERT				
HOR				

SEAL CONDITION

HOW MANY (IF ANY) SEAL BOLTS ARE MISSING? ____________________________
RECORD LOCATION AND LENGTH OF DAMAGED (D) OR MISSING (M) SECTIONS

	COND'N-D,M	LOC'N-T,B,L,R	LENGTH (in.)	DIST. FROM TOP/LEFT (ft)
(1):				
(2):				
(3):				
(4):				
(5):				

CRACKING

COMPONENT: SKIN (S), OPERATING ARM & EYE (A), END PLATE (E), SEAL PLATE (P)

	COMPONENT	LENGTH (in.)	LOCATION
(1):			
(2):			
(3):			
(4):			
(5):			

CORROSION	P OR N	SECT THICK	MAX DEPTH	AVG DEPTH	%AREA OR NO. PITS	AVG DIA
US BODY						
DS BODY						
OPERATING ARMS						
OPERATING EYES						
END PLATES						
SEAL PLATES						

LIFTING BRACKET OPERATING MECHANISM WEAR

LOWER STRUT END: CLOSED (in.) __________________ JUST LIFTED (in.)

OPERATING EYES:	CLOSED (in.)	JUST LIFTED (in.)
TOP LEFT		
TOP RIGHT		
BOTTOM LEFT		
BOTTOM RIGHT		

Page 3D Comments: Field data.

Complete at site inspection.

AXLE ASSEMBLY WEAR: Indicate if the bushing rotates. If it does, indicate if the bushing is completely seized to the trunnion pin. This is done by monitoring the bushing as the valve is rotated through a full range of motion. Indicate if there is any evidence of the valve dragging on the side walls, including grooves or marks on the culvert walls. Measure the lifting strut spring compression as the valve rotates through a full cycle. Record the maximum spring compression and what percent the valve is closed when the maximum reading is recorded. Also record the design specified spring compression. Take wear measurements in horizontal and vertical directions, using dial gauges. Record the measurements with the valve in four different positions: (1) initial position before jacking, (2) jacked downstream, (3) jack released, and (4) jacked upstream.

SEAL CONDITION: Record the number of missing seal bolts. This number is not used in the CI calculation, but is used for reference. Record any damaged or missing sections of seal and record the location as, top (T), bottom (B), left (L), or right side (R). A section of seal is considered damaged if it is cracked, ripped, or improperly attached. Missing sections refer to complete sections broken off because of debris, age, or other causes. Also record the length and location of each entry. Measure the length with a ruler and indicate the location in reference to the top or left side of the valve.

CRACKS: Determine the location and length of cracks on the skin plate, operating arms and eyes, end plate, and seal plate with a ruler or tape measure. The location of the crack should be adequately described for repair purposes and future comparisons. For example, note if the crack occurs in the connection or main member.

CORROSION: For each component, first indicate if the data will be entered by counting the number of pits, N, or by estimating the percentage, P, of the area affected. Estimate or check drawings for the original section thickness. Record the maximum pitting depth. This entry is not used in the CI calculation, but is for reference purposes only. Next, select an area of 1 square foot of corrosion on each component. This area should characterize the maximum density of average depth corrosion. Record the average pitting depth for each area. For the next data column, record either the percentage of the pitted area or count the actual number of representative pits. In the last column, if the data was entered by counting the number of pits, record the average diameter of the representative pits. In some cases, when the percentage area method is used and the deterioration is uniform, the percentage of area affected is 100 percent and the average pitting depth is the average thickness reduction.

LIFTING BRACKET BUSHING WEAR: Measure wear at five locations: the lower end of the lifting strut and each of the four points where the operating arms connect to the operating eyes. Measure the lifting strut bushing wear using a gauge or ruler to measure the relative movement as the valve is initially lifted, or a feeler gauge to measure the gap between the pin and bushing. If using a ruler or dial gauge, begin with the valve tightly closed and record an initial reference value. Then lift the valve off the floor and take a second reading. The simplest way to measure the wear at the operating arm connection points is to use feeler gauges. Record measurements at the top, bottom, and sides, and the maximum value recorded. Enter a zero in the CLOSED blank and the maximum gap in the JUST LIFTED blank.

(Complete for wet only)

OPENING AND CLOSING OF THE VALUE

			% CLOSED
IRREGULAR VIBRATION?	Y	N	______
IRREGULAR NOISE?	Y	N	______
DOES THE VALVE JUMP?	Y	N	______

AXLE ASSEMBLY WEAR

	LEFT SIDE		RIGHT SIDE	
DOES BUSHING ROTATE WITH PIN?	Y	N	Y	N
IF YES, IS BUSHING SEIZED TO PIN?	Y	N	Y	N
IS THERE EVIDENCE OF DRAGGING?	Y	N	Y	N

MAX. SPRING COMPRESSION ______ % CLOSED ______
DESIGN SPECIFIED SPRING COMPRESSION ______

ESTIMATE WEAR FROM MEASUREMENT PROJECTION:

	AXLE (in.)	BUSHING (in.)
MAXIMUM WEAR	______	______

SEAL CONDITION
HOW MANY (IF ANY) SEAL BOLTS ARE MISSING? ______
R[illegible]D LOCATION AND LENGTH OF DAMAGED (D) OR MISSING (M) SECTIONS

	COND'N-D,M	LOC'N-T,B,L,R	LENGTH (in.)	DIST. FROM TOP/LEFT (ft)
(1):	______	______	______	______
(2):	______	______	______	______
(3):	______	______	______	______
(4):	______	______	______	______
(5):	______	______	______	______

CORROSION	P OR N	SECT THICK	MAX DEPTH	AVG DEPTH	%AREA OR NO. PITS	AVG DIA
US BODY	______	______	______	______	______	______
DS BODY	______	______	______	______	______	______
OPERATING ARMS	______	______	______	______	______	______
OPERATING EYES	______	______	______	______	______	______
END PLATES	______	______	______	______	______	______
SEAL PLATES	______	______	______	______	______	______

LIFTING BRACKET OPERATING MECHANISM WEAR

IS THERE EVIDENCE OF WEAR AT LOWER END OF STRUT? Y N
IF YES, APPROXIMATE MOVEMENT (in.)? 1/16 1/8 1/4

IS THERE EVIDENCE OF WEAR IN OPERATING EYES? Y N
IF YES, APPROXIMATE MOVEMENT (in.)?

TOP LEFT:	1/16	1/8	1/4
TOP RIGHT:	1/16	1/8	1/4
BOTTOM LEFT:	1/16	1/8	1/4
BOTTOM RIGHT:	1/16	1/8	1/4

Page 3W Comments: Field data.

Complete at site inspection.

OPENING AND CLOSING OF THE VALVE: Observation of any portion of the unsubmerged valve or lifting equipment during operation is often a good indicator of problems. Indicate by circling the proper answer whether or not the valve or its lifting equipment exhibits any unusual vibration, noise, or jumping. Also record the approximate position where these problems occur.

AXLE ASSEMBLY WEAR: Indicate whether the bushing rotates or is seized to the axle. This is done by monitoring the valve through a full range of motion. Indicate if there is any evidence of the valve dragging on the side walls, including grooves or marks on the culvert walls. Measure the lifting strut spring compression as the valve rotates through a full cycle. Record the maximum spring compression and what percent the valve is closed when the maximum reading is recorded. Also record the design specified spring compression. For measurement projection information, refer to Appendix A. From the plots of maximum axle and bushing wear, approximate measurements can be selected, depending on the number of lockages for the valve.

SEAL CONDITION: Record the number of missing seal bolts. Record any damaged or missing sections of seal and record the location, top (T), bottom (B), left (L), or right side (R). A section of seal is considered damaged if it is cracked, ripped, or improperly attached. Missing sections refer to complete sections broken off because of debris, age, or other causes. Also, record the length and location of each entry. Measure the length with a ruler and indicate the location in reference to the top or left side of the valve.

CORROSION: For each component, first indicate if the data will be entered by counting the number of pits, N, or by estimating the percentage, P, of the area which is affected. Estimate or check drawings for the original section thickness. Record the maximum pitting depth. This entry is not used in the CI calculation, but is for reference purposes only. Next, select an area of 1 square foot of corrosion on each component. This area should characterize the maximum density of average depth corrosion. Record the average pitting depth for each area. For the next data column, record either the percentage of the pitted area or count the actual number of representative pits. In the last column, if the data was entered by counting the number of pits, record the average diameter of the representative pits. In some cases, when the percentage area method is used and the deterioration is uniform, the percentage of area affected is 100 percent and the average pitting depth is the average thickness reduction.

LIFTING BRACKET BUSHING WEAR: Measure wear at five locations: the lower end of the lifting strut and each of the four points where the operating arms connect to the operating eyes. The simplest procedure is to make the necessary wear measurements at all five locations with feeler gauges. If feeler gauges cannot be used, an alternative method is possible. With a diver watching or feeling the pickup point connections, engage the lifting equipment enough to let the compression out of the lifting strut spring. Repeat this procedure for each location and indicate if there is any evidence of wear. If so, estimate how much by circling the appropriate value.

PART III: CONDITION INDEX

33. Determining a condition index involves engineering judgement and depends on the experience of the person making the evaluation. To define the criteria for a condition index, experts in the field were interviewed, and discussion continued until a general approach for valve inspections began to develop. Preliminary field visits and interviews with engineers were conducted at Locks and Dams 14, 15, and 24 on the Mississippi River; Fort Loudoun, Melton Hill, and Wilson Locks and Dams on the Tennessee River; and Lock and Dam 2 and Hildebrand Lock and Dam on the Monongahela River. The authors have attempted to blend all the opinions expressed at these meetings into a set of "expert opinion" rules embedded in the evaluation that determines the condition index. The rules have been designed to interpret straightforward, visual observation data in much the same manner that a seasoned engineer would interpret field observations. The experts took many factors into account as they evaluated the CI. These factors included serviceability or performance and a subjective evaluation of safety. The rules will continue to evolve.

34. A series of measurements, projections, or subjective evaluations were made on each valve to quantify the CI. Experts were asked to interpret these measurements in light of the serviceability and safety of the valve and to assign limiting values to the measurements. Specifically, a series of distresses was identified and each distress was quantified by a measurement X. For example, anchorage assembly deterioration is a distress partially quantified in a dry inspection by the relative motion of the steel base plate with respect to the concrete.

35. Typically, each distress can be either a problem in itself or an indication of a problem. For example, anchorage movement is a problem in itself if it is sufficiently large to impede valve operation; otherwise it can be an indication of a potential structural problem. The individual distress CI is quantified by

$$\text{Condition Index} = 100(0.4)^{X/X_{max}} \qquad \text{[Eq 3.1]}$$

where X_{max} is some limiting value of X (Greimann and Stecker, 1989). The previous description of condition index zones (Table 1) defines X_{max} as the point at which the condition index is 40; that is, the dividing point between Zones 2 and 3. Figure 16 illustrates the equation and zones from Table 1. Experts have selected X_{max} to be the point at which the valve requires immediate repair or, at least, a more detailed inspection than that described herein.

Distress Descriptions and X_{max}

36. If a valve structure is designed and constructed properly, it has an initial CI of 100. As time passes and the structure is exposed to varying environmental and operational situations, its condition will deteriorate and the CI will be lower. Eight distresses for tainter valves and six distresses for butterfly valves have been identified for categorization in this project. Some of the distresses are not measured in both wet and dry inspections. The distresses are identified and described briefly in Tables 2 and 3 for tainter and butterfly valves, respectively.

37. In the following sections, potential causes of each distress are also listed and discussed. These causes are the problems that must be addressed in the maintenance and repair of the valve. Diagnosing the causes for each distress is a complex issue. Many times a distress may have several possible causes, and often a combination of distresses must be present before a certain cause can be identified. Typically, causes are similar for tainter and butterfly valves.

38. Measurement of X and limiting X_{max} values for each distress are also described in the following sections. Often, tainter and butterfly valves have the same measurement and limiting value, such as corrosion/pitting/

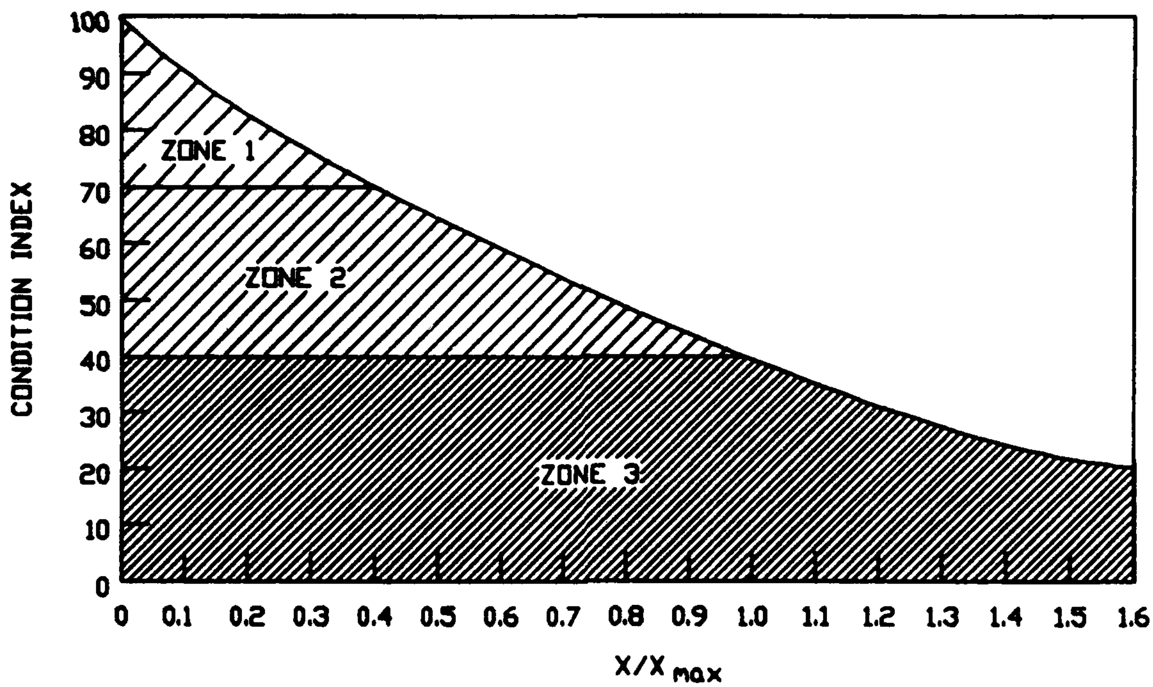

Figure 16. Condition index related to X/X_{max}

Table 2

Tainter Valve Distresses

Distress	Description
Anchorage assembly deterioration	Movement of embedded anchorage system and damaged components
Trunnion assembly wear	Displacement between pin and bushing
Seal condition	Condition of seals in place
Corrosion	Loss of steel due to interaction with the environment
Cavitation/Erosion/ Abrasion	Jagged pitting
Lifting bracket bushing wear	Displacement between pin and bushing on the lifting bracket
Cracking (Dry inspection only)	Breaks in structural steel components
Noise/Jump/Vibration (Wet inspection only)	Abnormal noise, jumping, or vibration during valve operation

Table 3

Butterfly Valve Distresses

Distress	Description
Axle assembly wear	Displacement between the axle and bushing
Seal condition	Condition of seals in place
Corrosion	Loss of steel due to interaction with the environment
Lifting bracket operating mechanism wear	Displacement between pin and bushing on the lifting bracket
Cracking (Dry inspection only)	Breaks in structural steel components
Noise/Jump/Vibration (Wet inspection only)	Abnormal noise, jumping, or vibration during valve operation

erosion/abrasion. In other cases, such as trunnion or axle assembly wear, different rules apply. For this reason, each of the following Measurement and Limits sections have a separate subsection for tainter and butterfly valves.

Anchorage Assembly Deterioration Distress

Definition and Causes

39. Anchorage assembly deterioration represents the displacement of the embedded anchorage system and the current condition of the assembly components, especially the trunnion casting and anchorage bolts. Movement can occur during opening and closing of the valves and during filling and emptying of the lock chamber. Anchorage deterioration can be caused by:

- corrosion
- concrete cracking and spalling
- anchor bolt elongation or movement
- loose or missing casting bolts
- additional load.

The anchorage system on either side of the culvert is the only mechanism that connects the valve to the concrete wall. Hence, the presence of anchorage movement may indicate a significant structural problem, or it could eventually introduce structural problems into other valve components. In addition, corroded, loose, or missing casting and anchorage bolts and nuts can cause irregular movement of the valve, introducing functional and structural problems into various components.

Measurement and Limits

40. Tainter. If anchorage movement becomes significant, it can be detected by visually inspecting the interface for a line where the corrosive buildup is broken. This can be detected in a wet or dry inspection and is usually the first indicator of a significant problem. When using the dry inspection procedure, measurement of the anchorage movement is made between the concrete and the trunnion bearing plate using dial gauges (Figure 12). The measurement is made perpendicular to the concrete to detect elongated or broken anchor bolts, or loose anchor nuts. The maximum motion that occurs at the concrete interface, X, is found by finding the difference between the open and closed measurements for the top and bottom locations. The presence of cracked or spalled concrete and the current condition of the anchor and casting bolts and nuts are also recorded.

41. A displacement of 0.005 in. has been selected as the limiting motion at the steel and concrete interface

$$X_{max} = 0.005\ in. \qquad [Eq\ 3.2]$$

The experts judged that motion greater than this could indicate a significant structural problem. Any structural cracking or spalling of the concrete in this area will reduce the condition index by a factor of 0.65. If any of the bolts or nuts are significantly corroded, the CI decreases by a factor of 0.65. If any of the anchor or casting nuts are loose, the CI is reduced by a factor of 0.55. If any bolts or nuts are broken or missing, the CI is decreased by a factor of 0.40. If there are both loose and missing bolts, only the 0.40 factor is used.

42. Example. From dial gauge readings, a valve anchorage assembly has the following maximum movement.

$$X = 0.001\ in.$$

Cracked and spalled concrete was evident around the bearing plate. The CI for anchorage assembly deterioration is

$$CI = [100(0.4)^{0.001/0.005}]0.65 = 54$$

where the 0.65 factor was used because the concrete was cracked and spalled. From Table 1, the CI is rated fair; that is, there is moderate deterioration of the anchorage.

43. The wet inspection is very similar to the dry inspection except no actual movements are measured. A diver checks for cracked and spalled concrete, corroded anchor and casting bolts and nuts, loose anchor and casting nuts, and broken anchor and casting bolts and nuts. If any of these are evident, an initial CI of 100 is then decreased by the same factors as for the dry inspection.

44. Example. A diver determines that cracked and spalled concrete was evident around the bearing plate. Also, the diver discovers a loose nut on one of the bearing cap bolts. The CI for anchorage assembly deterioration is

$$CI = (100)(0.65)(0.55) = 36$$

where the 0.65 factor reduced the CI because of cracked and spalled concrete and the 0.55 factor reduced the CI because of a loose nut on the bearing cap. From Table 1, the CI is rated as poor; that is, there is serious deterioration present and the function could be significantly impaired.

45. Butterfly. Because the entire center frame anchorage assembly is embedded in concrete, experts have judged that negligible movement occurs at the steel and concrete interface. Therefore, the anchorage assembly deterioration distress is not evaluated for butterfly valves.

Trunnion/Axle Assembly Wear Distress

Definition and Causes

46. Trunnion assembly wear refers to the total relative movement of the trunnion pin or axle with respect to the casting that houses the bushing. This movement takes place while the valve rotates through its normal range of motion and when the valve is loaded during filling and emptying of the lock chamber. Trunnion assembly wear can occur between the pin or axle and the bushing or, if the bushing rotates, between the bushing and the casting. It can be caused by several factors:

- improper lubrication
- large number of lockages
- jumping and vibration
- broken keyway or sheared pins on bushing.

Measurement and Limits

47. Tainter. For a dry inspection, horizontal and vertical dial gauge readings are recorded with the valve jacked in four different positions (Figures 14 and 15):

(1) initial
(2) jacked downstream
(3) jack released
(4) jacked upstream.

The maximum displacement occurs between positions (2) and (4). Hence, the X value in each direction for trunnion assembly wear was chosen as:

$$X_{HOR} = X_{(2)HOR} - X_{(4)HOR}$$
$$X_{VER} = X_{(2)VER} - X_{(4)VER} \qquad \text{[Eq 3.3]}$$

The total wear is calculated by taking the square root of the sum of the squares of the wear in each direction:

$$X_{TOT} = \sqrt{(X_{HOR})^2 + (X_{VER})^2} \qquad \text{[Eq 3.4]}$$

The limiting X_{max} value for trunnion assembly wear was judged to be:

$$X_{max} = 0.188 \ in. \qquad \text{[Eq 3.5]}$$

48. The condition of the lubricating system and the existence of any bushing rotation is recorded on the inspection form. If the lubrication system is not functioning properly, it may not be critical, but over a long period of time it can cause accelerated wear in the trunnion assembly. Therefore, a reduction factor of 0.85 is used if lubrication is inadequate.

If the trunnion bushing rotates, either a pin or keyway has been sheared. Over time, if the bushing rotates, the bushing may become seized to the trunnion pin. This can cause wear on the outer surface of the bushing. If the bushing simply rotates, it usually is not critical and the CI is reduced by 0.85. If the bushing rotates and is seized to the pin, more problems may be involved and the CI is reduced by a factor of 0.70. This puts the trunnion into Zone 2, which indicates some maintenance action should be investigated.

49. Example. From the inspection measurements with the valve jacked, the following maximum movements were calculated from the difference in the readings in positions (2) and (4) as shown in Equation 3.3:

$$X_{HOR} = 0.060\ in.$$

$$X_{VER} = 0.032\ in.$$

The total diagonal movement is found by using X_{HOR} and X_{VER} in Equation 3.4:

$$X_{TOT} = \sqrt{(0.060)^2 + (0.032)^2} = 0.068\ in.$$

Upon inspection it was found that the lubrication system was leaking grease and the bushing rotated during operation, but was not seized to the trunnion pin. Therefore, the CI for trunnion assembly wear is:

$$CI = [100(0.4)^{0.068/0.188}](0.85)(0.85) = 52$$

The 0.85 factors were used because of problems with the lubrication system and bushing rotation. This puts the valve in fair condition with the function not seriously impaired.

50. A wet inspection evaluation is very similar to the dry. If it is possible to use feeler gauges, measurements are recorded in four locations:

(1) top
(2) bottom
(3) upstream
(4) downstream.

Horizontal and vertical X values are calculated by adding the feeler gauge readings in each direction.

$$X_{HOR} = X_{Upstream} + X_{Downstream} \qquad \text{[Eq 3.6]}$$

$$X_{VER} = X_{Top} + X_{Bottom}$$

The total movement is calculated by substituting these X values into Equation 3.4. The reduction factors for disfunctional lubricating system, rotating bushing, and seized bushing are 0.85, and 0.70, respectively, similar to the dry inspection.

51. If the diver is unable to use feeler gauges and projected measurements are used, X is found by adding the projected values for pin and bushing wear on the inspection form. To obtain a conservative CI using less reliable projection measurement information, the reduction factors for a disfunctioning lubrication system and bushing rotation are more severe. If the lubrication system is not functional, the CI is decreased by a factor of 0.70; if the bushing rotates without seizing to the pin, the CI is decreased by 0.70; and if the bushing is seized, a factor of 0.55 is used.

52. Example. Feeler gauges could not be used by the diver so measurement projection is necessary. The approximate number of lockages is 50,000. From Figures A1 and A2, the estimated pin and bushing wear is 0.005 in. and 0.02 in., respectively. The total projected wear, X_{TOT}, is 0.025 in. The CI for a wet inspection of the trunnion assembly wear is:

$$CI = [100(0.4)^{0.025/0.188}](0.70)(0.70) = 43$$

where the 0.70 factors have been used because of problems with the lubrication system and bushing rotation. From Table 1, this valve is rated in fair condition.

53. Butterfly. A dry inspection of butterfly valves follows the tainter valve dry inspection procedure. The valve is jacked using the same procedure and the X and X_{max} values do not change. The reduction factors for rotating bushing and seized bushing are 0.85 and 0.70, respectively, as with tainters. Dragging of the valve on the sides of the culvert wall indicates severe axle assembly wear, and a reduction factor of 0.40 is used. Dragging can be indicated by either grooves on the culvert wall or overcompression of the spring in the lifting strut. Overcompression occurs if the measured compression of the spring before closure of the valve is greater than the specified design value. If more than one of the above conditions occur, e.g., rotating bushing and dragging, only the smallest reduction factor is applied.

54. The wet inspection of butterfly valves is also very similar to the wet inspection of tainter valves. In most circumstances, though, the butterfly valve shoulder prevents the use of feeler gauges. Therefore, measurement projection values from Figures A3 and A4 are used more frequently, and X is found by adding the axle and bushing measurements together. The X_{max} and the reduction factors are the same as for dry inspection.

Seal Condition Distress

Definition and Causes

55. When seals are damaged or sections are missing, it allows water to leak around the perimeter of the valve. At locations where the normal head is less than approximately 30 ft, a limited amount of leaking can be tolerated

because it does not present significant functional or structural problems. Excessive seal wear at these locations can indicate problems with the anchorage, hinge, or lifting systems of the valve. For example, wear between the trunnion, or axle assembly wear could allow the valve to move laterally in the culvert, causing the valve to bind and wear the seals excessively. At locations where the normal head is greater than 30 ft, concrete adjacent to the seals can be severely damaged from erosion if the valve does not seal properly. Therefore, seal damage is much more critical in high lift situations. Seal damage and leakage are caused by several factors:

- floating debris
- improper valve alignment
- improper lifting
- corroded seal plates
- normal use over time.

<u>Measurement and Limits</u>

56. <u>Tainter</u>. Regardless of the type of inspection being performed (wet or dry), the procedure for seal inspection is generally the same. Seals are visually inspected for damaged and missing sections and the lengths, L_D and L_M, and locations are recorded. The X_D and X_M values for damaged and missing sections of seal are

$$X_D = \text{Sum of } L_D$$
$$X_M = \text{Sum of } L_M \qquad \text{[Eq 3.7]}$$

57. The limiting lengths for damaged and missing seals are based on the normal amount of lift at a particular site and are defined as a percentage of the total perimeter length of seal (Figure 17). For missing sections, at locations that have a normal head less than 30 ft,

$$X_{maxM} = 0.15 \times \text{Perimeter length} \qquad \text{[Eq 3.8]}$$

If the normal head is greater than 30 ft and less than 60 ft,

$$X_{maxM} = \frac{.50(60 - \text{normal lift})}{100} \times \text{Perimeter length} \qquad \text{[Eq 3.9]}$$

If the normal lift is greater than 60 ft, even a small amount of leakage can be very damaging to the sealing surfaces and the adjacent concrete. Therefore, the condition is poor and a detailed evaluation is required. To indicate this, the condition index will be

$$CI_M = 30 \qquad \text{[Eq 3.10]}$$

The condition index for all heads will not be less than 30.

58. For damaged sections at locations that have a normal head of less than 30 ft,

$$X_{maxD} = 0.30 \ x \ Perimeter \ length \qquad \text{[Eq 3.11]}$$

If the normal head is greater than 30 ft and less than 70 ft,

$$X_{maxD} = \frac{0.75(70 - normal \ lift)}{100} \ x \ Perimeter \ length \qquad \text{[Eq 3.12]}$$

If the normal head is greater than 70 ft, damaged seals may cause some leaking, which is critical in high lift situations. Therefore, the condition is poor and a detailed evaluation is required. To indicate this, the condition index will be

$$CI_D = 30 \qquad \text{[Eq 3.13]}$$

The condition index for all heads will not be less than 30. The CI describing the seal condition is the minimum of the damaged and missing seal CIs.

$$CI = Minimum(CI_M, CI_D) \qquad \text{[Eq 3.14]}$$

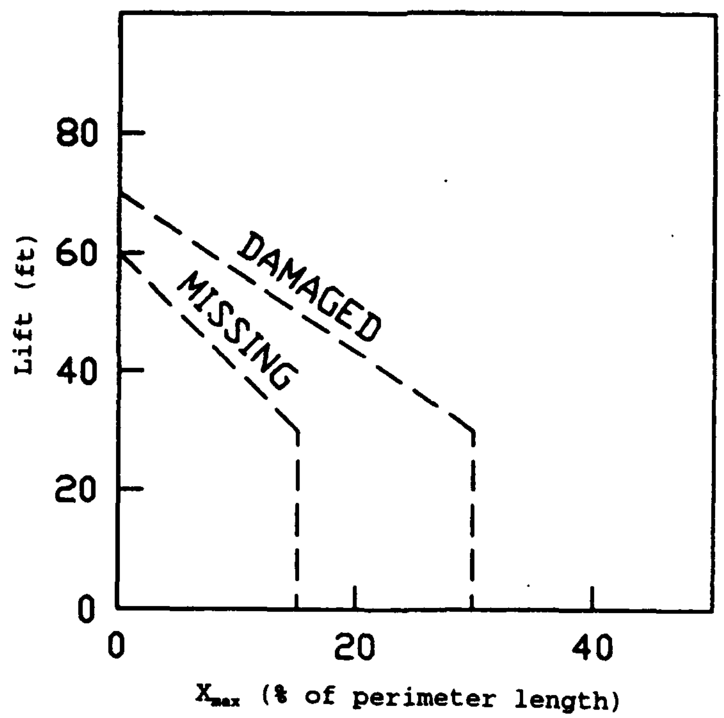

Figure 17. X_{max} for seal condition distress

59. Example. A site with a normal head of 40 ft is inspected. The culverts are 10 ft square and the following seal conditions are recorded.

Damaged: 6 in., 18 in., 12 in.

Missing: 24 in.

From Equation 3.7,

$$X_D = 36\ in. = 3\ ft$$
$$X_M = 24\ in. = 2\ ft$$

From Equations 3.9 and 3.12,

$$X_{maxM} = \frac{0.50(60 - 40)}{100} \times 30\ ft = 3.0\ ft$$
$$X_{maxD} = \frac{0.75(70 - 40)}{100} \times 30\ ft = 6.75\ ft$$

The CI for missing seal sections is

$$CI_M = 100(0.4)^{2/3} = 54$$

The CI for damaged seal sections is

$$CI_D = 100(0.4)^{3/6.75} = 67$$

The CI for seal condition in general is

$$CI = Minimum(54, 67) = 54$$

From Table 1, the CI for seal condition is described as being fair.

60. Butterfly. The evaluation procedure for wet and dry inspections of the seals is the same as for tainter valves.

Cracking Distress

Definition and Causes

61. The cracking distress is only evaluated during a dry inspection. Cracks usually represent a narrow opening, break, or discontinuity in the structural steel members. Cracks are caused by fatigue, brittle fracture, or overstressed structural steel components. Obviously, cracks have significant structural implications, because they can continue to grow if the cause of the overstress still exists or if the remaining steel cross section cannot carry the normal loads.

Measurements and Limits

62. Tainter. The number of cracks in the skin (S), strut arms and bracing (A), skin framing (F), or segmental girders (G) are recorded on the

inspection form. Size and location of cracks are also recorded but are not used in the calculation of the CI. It is implicitly assumed that very large cracks do not occur at the time of inspection. Such cracks would be recognized and repaired immediately because of the possible consequences. The limiting values for strut arm and bracing, segmental girder, skin plate, and skin framing cracks are

$$X_{maxA} = 1 \qquad \text{[Eq 3.15]}$$

$$X_{maxG} = 1 \qquad \text{[Eq 3.16]}$$

$$X_{maxS} = 1 \qquad \text{[Eq 3.17]}$$

$$X_{maxF} = 1 \qquad \text{[Eq 3.18]}$$

that is, a single crack at any location is considered critical.

63. The CI for all cracks is taken as the minimum of skin, skin framing, strut arm and bracing, and segmental girder values.

$$CI = Minimum(CI_S, CI_F, CI_A, CI_G) \qquad \text{[Eq 3.19]}$$

64. Example. The following number of cracks were counted on a valve.

$$X_S=1$$
$$X_A=0$$
$$X_F=0$$
$$X_G=0$$

The CI for skin plate cracks is

$$CI_S = 100(0.4)^{1/1} = 40$$

The CI for strut arm and bracing cracks is

$$CI_A = 100(0.4)^{0/1} = 100$$

The CI for skin plate framing cracks is

$$CI_F = 100(0.4)^{0/1} = 100$$

The CI for segmental girder cracks is

$$CI_G = 100(0.4)^{0/1} = 100$$

The CI for all cracks is

$$CI = Minimum(40,100,100,100) = 40$$

From Table 1, the CI is rated as fair; moderate deterioration is present, but the function is not seriously impaired.

65. Butterfly. The procedure for evaluating cracks on butterfly valves is similar to tainter valves, except different components are evaluated. The number of cracks in the skin (S), operating arms and eyes (A), end plates (E), and seal plates (P) are recorded. The limiting value for each component is

$$X_{maxS} = 1 \qquad [Eq\ 3.20]$$

$$X_{maxA} = 1 \qquad [Eq\ 3.21]$$

$$X_{maxE} = 1 \qquad [Eq\ 3.22]$$

$$X_{maxP} = 1 \qquad [Eq\ 3.23]$$

The CI for all cracks is taken as the minimum of skin, operating arm and eye, end plate, and seal plate cracks.

$$CI = Minimum(CI_S, CI_A, CI_E, CI_P) \qquad [Eq\ 3.24]$$

Corrosion Distress

Definition and Causes

66. Corrosion involves the uniform loss of steel material on a valve structure due to interaction with the environment. Pitting is a result of corrosion. Varying rates of degradation exist, depending on the length of time the valve has been submersed, the site-specific water conditions (chemistry and abrasive material content), and the normal amount of head on the structure.

67. Localized deterioration also takes place in the form of galvanic corrosion. When dissimilar metals are placed in a conductive solution, a potential difference exists. This situation arises when valves, constructed primarily of structural steel, have stainless steel components attached. Structural steel has a different electrical potential than stainless and electron flow is toward the more resistant material. Therefore, structural steel acts as the anode and stainless steel as the cathode.

68. Most light corrosion has little structural significance. However, extensive deterioration can sufficiently reduce the steel cross-sectional area so stresses are significantly increased.

Measurement and Limits

69. Tainter. To measure the amount of material loss due to corrosion, select the 1 square foot with the greatest material loss. Record the average pitting depth, D, and the average pitting diameter, d. Within the square foot, record either the percent of area affected or the number of pits. Record corrosion information for the upstream skin (US), downstream skin (DS), strut arm and bracing (A), skin framing (F), segmental girder (G), and the steel at the sealing surfaces (SS). The X value for this distress is the percent volume of steel loss due to corrosion. Use Equation 3.25 to determine the percent volume loss, X, based on the percent pitting, P, of the selected square foot.

$$X = \frac{P \times D}{T} \qquad \text{[Eq 3.25]}$$

T is the steel plate thickness. If the approximate number of pits, N, is recorded, the average pit diameter is also recorded. The affected area is

$$Area\ of\ 1\ pit = \pi \times Radius^2$$

$$= \frac{\pi\, d^2}{4} \qquad \text{[Eq 3.26]}$$

Since there are N pits with an average depth, D, the volume loss is

$$Volume\ loss = \frac{N \times \pi \times d^2 \times D}{4} \qquad \text{[Eq 3.27]}$$

If inch units are used to record the material loss, the percent volume loss is

$$X = 100 \times \frac{Volume\ loss}{144 \times T} \qquad \text{[Eq 3.28]}$$

The CI is based on the percentage volume loss, X. Independent of the component, the limiting value for section loss is equal to 20 percent of the original volume:

$$X_{max} = 20\% \qquad \text{[Eq 3.29]}$$

The CI for corrosion is the minimum of the CIs from all the components.

$$CI = Minimum(CI_{US}, CI_{DS}, CI_{A}, CI_{F}, CI_{G}, CI_{SS}) \qquad \text{[Eq 3.30]}$$

70. Example. A valve has a skin plate thickness of 3/8 in. During an inspection, the average pit depth is recorded to be 1/8 in. on the downstream skin and it is estimated that approximately 10 percent of the 1 square foot area is affected by the pitting. The percentage volume loss is calculated from Equation 3.25.

$$X_{DS} = \frac{10 \times 0.125}{0.375} = 3.3\%$$

The limiting value from Equation 3.29 is

$$X_{maxDS} = 20\%$$

The CI for the lower portion of the downstream skin is

$$CI_{DS} = 100(0.4)^{3.3/20} = 86$$

From Table 1, this CI is rated excellent.

71. Example. A valve has a skin plate thickness of 3/8 in. During an inspection, the average pit depth is recorded to be 1/8 in. on the downstream skin, the average diameter is 2.0 in., and five pits are recorded on the 1 square foot section. From Equation 3.27

$$Volume\ loss = \frac{5 \times \pi \times 2^2 \times 0.125}{4} = 1.96\ in^2$$

and the percent volume loss is calculated from Equation 3.28.

$$X_{DS} = 100 \times \frac{1.96}{144 \times 0.375} = 3.6\%$$

The limiting value from Equation 3.29 is

$$X_{maxDS} = 20\%$$

The CI for the lower portion of the downstream skin is

$$CI_{DS} = 100(0.4)^{3.6/20} = 85$$

From Table 1, this CI is rated excellent.

72. Butterfly. Evaluation of material loss for butterfly valves is the same as tainter valves, except different components are considered. The 20 percent volume loss rule is applied here also.

Cavitation/Erosion/Abrasion Distress

Definition and Causes

73. Erosion and abrasion are the results of cavitation. Erosion describes an accelerated rate of deterioration caused by movement between water and a metal. Abrasion is a mechanical wearing between two materials; in this case, steel and water-born particles. Cavitation is most likely to occur whenever the velocity of a liquid is high and the pressure is low. When the local pressure falls below the vapor pressure of the liquid, local vaporization occurs, causing cavities in the flow. The vapor bubbles are carried along by the flow until a region of high pressure is reached, where they suddenly collapse. This process is known as cavitation. In general, the effects of the collapsing cavities include noise, a jagged, dense pitting of the metal and concrete surfaces, and vibration of the system. Cavitation is most common on the lower one-third of the downstream skin plate, where water emerges under a partially opened valve. It is separated from ordinary corrosion because once it starts, the condition worsens at a much faster rate than corrosion.

Measurement and Limits

74. Tainter. The downstream skin plate is the primary location where cavitation damage occurs. Because cavitation causes such a rapid rate of deterioration, experts have judged that its very presence represents a significant deterioration. Therefore, if any cavitation is at all visible, the condition index is reduced to 65. Cavitation, when present, is measured by the maximum pitting depth, X. If this maximum depth is equal to 3/8 in., the condition index is reduced to 40. Therefore, the condition index is given by Equation 3.1 with

$$X_{max} = 3/8\ in. \qquad [Eq\ 3.31]$$

except that it cannot be greater than 65 if cavitation exists.

75. Example. From an inspection of a valve the maximum pit depth, X, is recorded to be 1/16 in. Using Equation 3.1 the CI for corrosion/erosion/abrasion is

$$CI = 100(0.4)^{0.0625/0.375} = 86$$

but this must be reduced to

$$CI = 65$$

since cavitation does exist. If the maximum pit depth had been 5/16 in., the CI would be

$$CI = 100(0.4)^{0.3125/0.375} = 47$$

76. Butterfly. It was judged by the experts that cavitation is generally not a problem with butterfly valves; therefore, it is not evaluated.

Lifting Bracket Bushing Wear Distress

Definition and Causes

77. Lifting bracket bushing wear causes relative movement between the pin and bushing at all pickup points on the valve. This movement generally takes place as the valve is initially lifted and during the final stages of the closing process as the valve is forced tightly closed to assure an adequate seal. The wear can be caused by several factors:

- improper lubrication
- large number of lockages
- jumping and vibration.

Measurement and Limits

78. Tainter. Regardless of the instrumentation used to measure the wear for a dry inspection, two values for each pickup point are recorded: valve closed, X_{Closed}, and valve initially lifted, X_{Lifted}. The maximum displacement occurs between these two positions. Hence, the X value for lifting bracket bushing wear with a single pickup point is

$$X = X_{Lifted} - X_{Closed} \qquad \text{[Eq 3.32]}$$

If there are pickup points on the left, L, and right, R, the X value is

$$X_L = X_{LiftedL} - X_{ClosedL}$$

$$X_R = X_{LiftedR} - X_{ClosedR} \qquad \text{[Eq 3.33]}$$

$$X = Maximum(X_L, X_R)$$

The limiting X_{max} value for lifting bracket bushing wear is 1/4 in.

$$X_{max} = 0.250\ in. \qquad \text{[Eq 3.34]}$$

If there is more than one pickup point, the CI is

$$CI = Minimum(CI_L, CI_R) \qquad \text{[Eq 3.35]}$$

79. Example. From a dry inspection of a valve with a single pickup point, the following measurements were recorded:

$$X_{Lifted} = 0.255$$

$$X_{Closed} = 0.150$$

From Equations 3.32 and 3.34,

$$X = 0.255 - 0.150 = 0.105$$

$$CI = 100(0.4)^{0.105/0.250} = 68$$

From Table 1, this CI is rated good.

80. A wet inspection evaluation is very similar to the dry, except there is a more limited number of measurement possibilities. The X value is the value circled on the inspection form and X_{max} remains at 1/4 in.

81. Butterfly. A dry inspection for lifting bracket bushing wear of butterfly valves is the same as for tainter valves, except more locations are considered. A lifting strut provides one pickup point on butterfly valves. In addition, measurements are recorded at each connection point provided by the operating arms. For each of the five locations, X is calculated using Equation 3.32 and individual CIs are calculated using in X_{max} value of 1/4 in. Similar to Equation 3.35, the overall CI for lifting bracket operating mechanism wear is the minimum of the individual CIs.

82. For a wet inspection, evaluation is the same as for tainter valves, except five locations are considered. There are a limited number of choices for X, and X_{max} remains at 1/4 in.

Noise, Jumping, and Vibration Distress

Definition and Causes

83. The noise, jumping, and vibration distress is only evaluated during a wet inspection. This distress represents abnormal valve sounds and motions during opening and closing of the valve and while the valve is stationary as the chamber is being filled or emptied. Valve noises, jumping, and vibration are caused by several factors:

- improper lubrication
- water passing through or around valve
- valve out of adjustment
- seals rubbing on seal plate
- floating debris.

Although a noise is often difficult to isolate and diagnose, abnormal noises should not be ignored because they commonly indicate a problem. Normal noises, jumping, and vibration include those caused by seals or operating machinery.

Measurement and Limits

84. Tainter. Noise is recorded when it occurs at a specific location as the gate is opened or closed. The presence of vibration and jumping at any point in the valve rotation is also recorded. Normal noise, jumping, and vibration occurrences are not used to reduce the CI. The CI for the possible combinations is shown below.

Noise, Jumping, or Vibration	CI
None	100
Yes for any one of the three	70
Yes for any two	40
Yes for all three	30

Obviously, this distress is more subjective and less quantifiable than the other distresses; however, its importance should not be minimized. Jumping, for example, can indicate structural problems, and abnormal noises almost always indicate behavior that should be investigated.

85. Example. As a valve was lifted, it made a popping noise at 75 percent closure. Also, a squealing noise due to the valve seals occurred throughout the valve operation. The CI is

$$CI = 70$$

because the valve seal noise is normal and is ignored in determining the CI. If the noise had not been due to the seals, the CI would have been 40. From Table 1, this CI is rated very good.

86. Butterfly. The table of CI values for tainter valves is also used for butterfly valves.

Multiple Distresses

87. When several distresses occur simultaneously, such as anchorage assembly deterioration and cracking, the CIs are combined into a single value. Weighting factors, w_i, are introduced to reflect the importance of the various individual distresses. The weighting factors assign more value to the more significant distresses. Relative initial weights for tainter and butter-fly valves, for both dry and wet inspections, are listed in Tables 4, 5, 6, and 7, respectively. They reflect, to some degree, the opinion of the Corps experts and, also, the opinions of the authors. Table 4, for example, shows that anchorage assembly deterioration is the most important and lifting bracket bushing wear is the least important distress for a dry inspection of tainter valves. The normalized weighting factors, W_i, are defined by

$$W_i = \frac{w_i}{\sum w_i} (100) \quad \text{[Eq 3.36]}$$

where

$$\sum W_i = 100$$

These normalized values are listed in the tables (rounded to add up to 100). The combined CI for all distresses is given by

$$CI = W_1 CI_1 + W_2 CI_2 + \ldots . W_n CI_n \ (3.37) \quad \text{[Eq 3.37]}$$

where n represents the total number of distresses evaluated, depending on the structure and type of inspection procedure.

Tat e 4
Unadjusted Weighting Factors for Tainter
Distresses (Dry Inspection)

Distress	w_i	W_i (%)
Anchorage assembly deterioration	10.0	25.0
Cracking	9.3	23.1
Trunnion assembly wear	6.3	15.6
Lifting bracket bushing wear	6.3	15.6
Seal condition	4.0	10.0
Cavitation/Erosion/Abrasion	3.3	8.2
Corrosion	1.0	2.5

Table 5
Unadjusted Weighting Factors for Tainter
Distresses (Wet Inspection)

Distress	w_i	W_i (%)
Anchorage assembly deterioration	10.0	27.9
Lifting bracket bushing wear	6.3	17.5
Trunnion assembly wear	6.3	17.5
Noise/Jump/Vibration	5.0	14.0
Seal condition	4.0	11.1
Cavitation/Erosion/Abrasion	3.3	9.2
Corrosion	1.0	2.8

Table 6
Unadjusted Weighting Factors for Butterfly
Distresses (Dry Inspection)

Distress	w_i	W_i (%)
Cracking	9.3	34.6
Lifting bracket operating mechanism wear	6.3	23.4
Axle assembly wear	6.3	23.4
Seal condition	4.0	14.9
Corrosion	1.0	3.7

Table 7
Unadjusted Weighting Factors for Butterfly
Distresses (Wet Inspection)

Distress	w_i	W_i (%)
Axle assembly wear	6.3	27.9
Lifting bracket operating mechanism wear	6.3	27.9
Noise/Jump/Vibration	5.0	22.1
Seal condition	4.0	17.7
Corrosion	1.0	4.4

88. Based on similar work done by the ISU project team (Greimann and Stecker, 1989), the concept was established that, as a distress became more severe, its relative importance became larger. To account for this, a variable adjustment factor was introduced to increase the distress weighting factor w_i as its CI approached Zone 3. The adjustment factor plotted in Figure 18 has a maximum value of eight; that is, if a distress has a CI less than 40, its importance increases eight times.

Field Testing

89. The performance of the rating rules was evaluated by comparing the calculated CI values based on the above rules to the CI values subjectively determined by Corps engineers who are valve experts. The expert engineers provided the guidance for establishing distress rules and observation ratings at a valve field test.

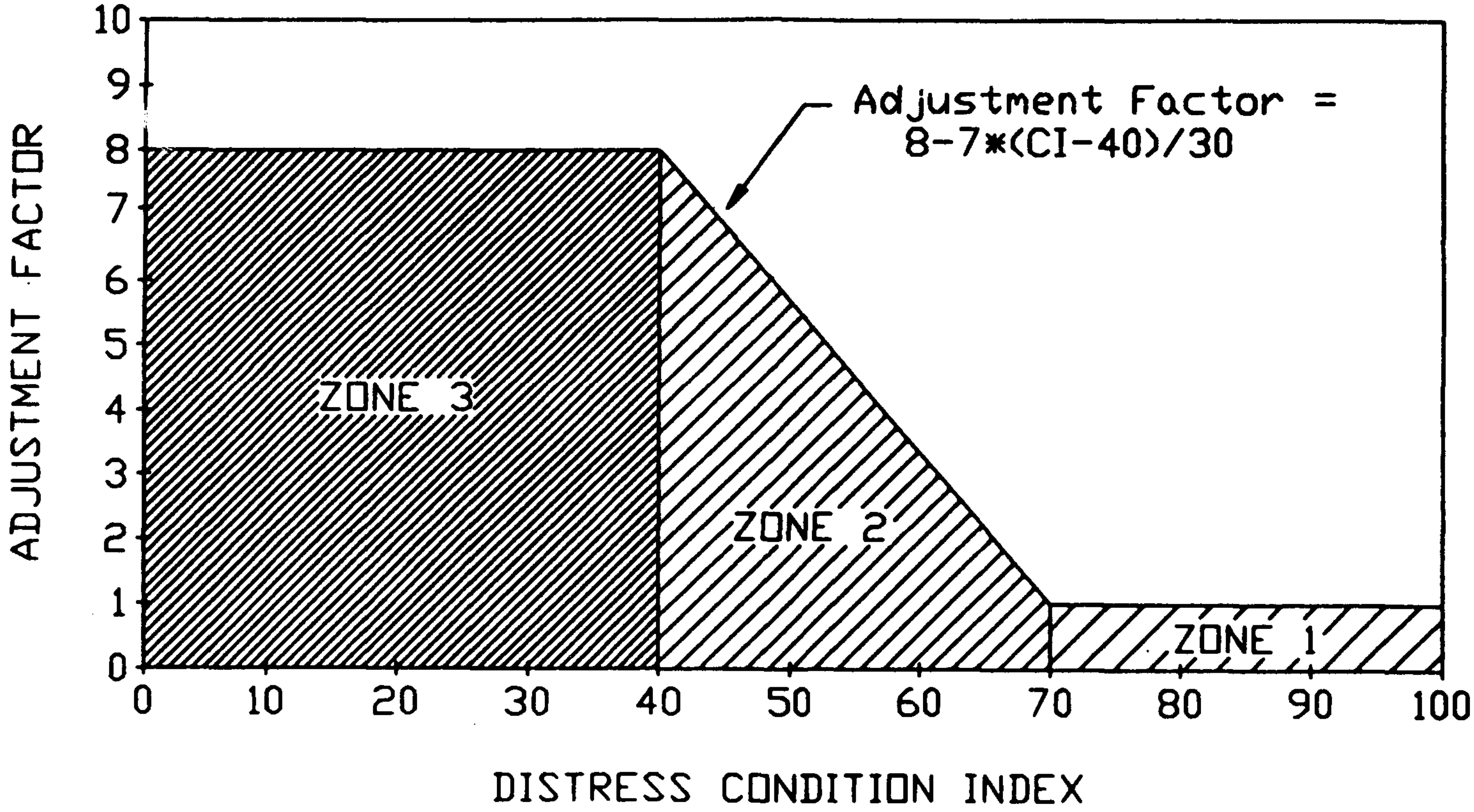

Figure 18. Weight adjustment factor for condition index

90. As summarized at the beginning of Part III, several site visits were conducted and Corps experts were interviewed to establish an initial set of condition index rules. The valve experts who participated in the initial rule development were Lynn Midgett (Nashville District), Jim Fisher (Pittsburgh District), and Mike Kruckeberg (Saint Louis District).

91. In April 1992, a wet inspection of the valves at Nickajack lock was performed by the Nashville District. The divers carried out the procedure, and the process was monitored and recorded from the surface using underwater video and audio equipment. The procedure was deemed a success; however, no calibration with expert judgements was performed.

92. In June 1992, a field test of dry tainter valves was conducted in the Nashville District. The same three experts were involved: Midgett, Fisher, and Kruckeberg. Two tainter valves were inspected at Wheeler Lock. The results of these field tests were used to make minor modifications and to calibrate the rating system for tainter valves. Each expert was asked to subjectively rate the individual distresses for the valves, that is, to assign a CI to each distress. Additionally, the experts were asked to assess an overall valve CI. Most of the comments and suggestions made during that test have been incorporated into the current version of the procedure. Some adjustments to X_{max} values and weighting values were made to better fit the experts' ratings. The previous portions of Part III include these changes.

93. The following bar charts (Figures 19 through 25) present the experts' subjective condition index versus the CI calculated by the rules discussed earlier for the seven distresses associated with a dry tainter inspection. One graph is presented for each distress. Within each group of data are four columns of data that represent

- expert average
- calculated CI (Chapter 3 rules)
- highest index assigned by an expert
- lowest index assigned by an expert.

The results of a comparison between the expert rating and the calculated values for each distress are summarized in the following paragraphs. Figure 26 shows a comparison for the overall index of the valve.

Anchorage Assembly Deterioration (Figure 19)

94. The calculated anchorage assembly CI for the emptying valve closely approximated the expert average. The calculated CI for the filling valve was 22 points lower than the expert average. After the experts had expressed their subjective ratings, a lengthy discussion concerning the significance of anchorage movement resulted in lowering the X_{max} value to 0.005 in. In other words, the experts judged that almost any measurable movement of the anchorage is a concern. After this discussion and modification, the experts did not

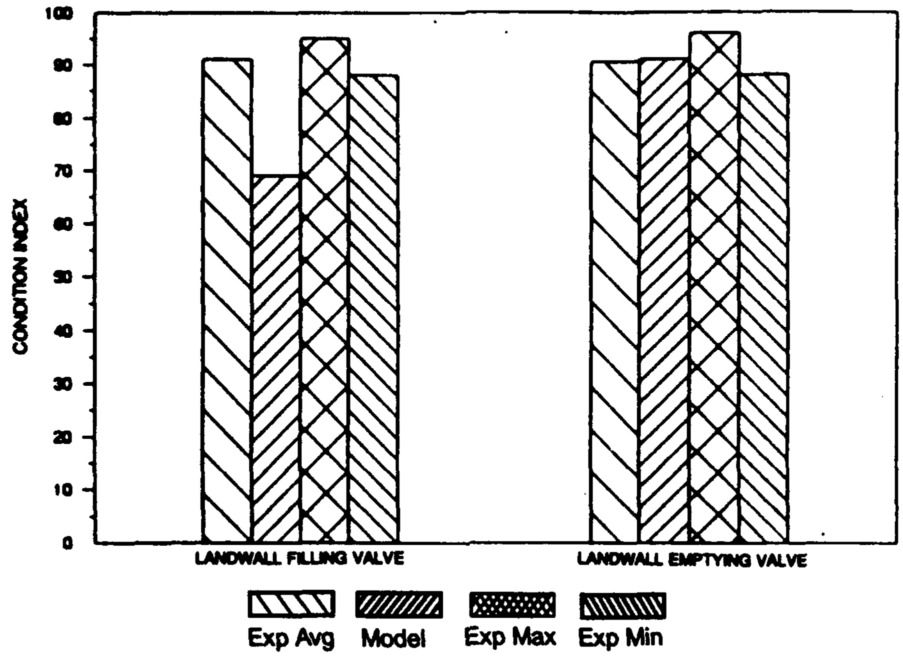

Figure 19. Anchorage assembly deterioration

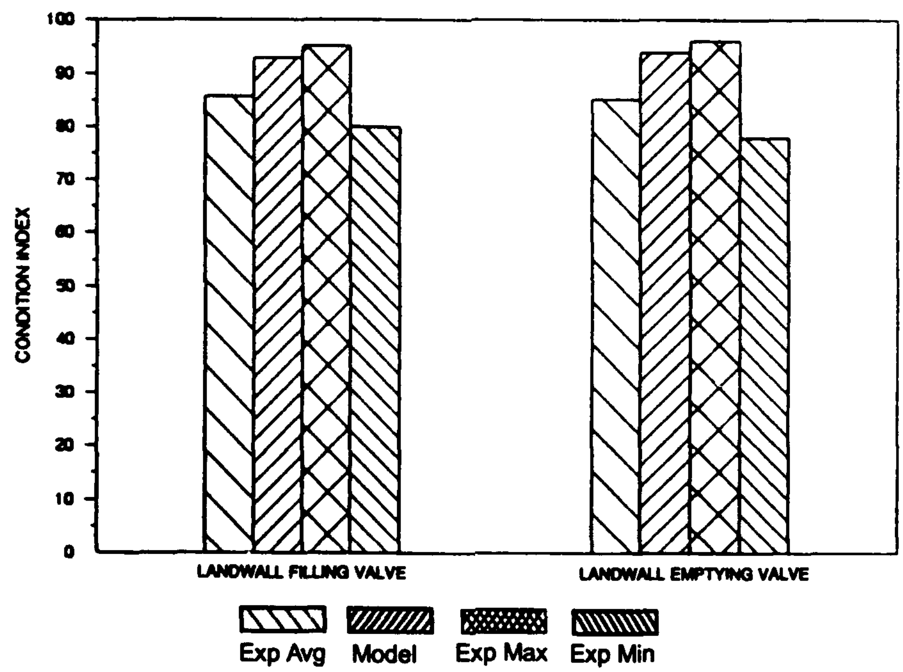

Figure 20. Trunnion assembly wear

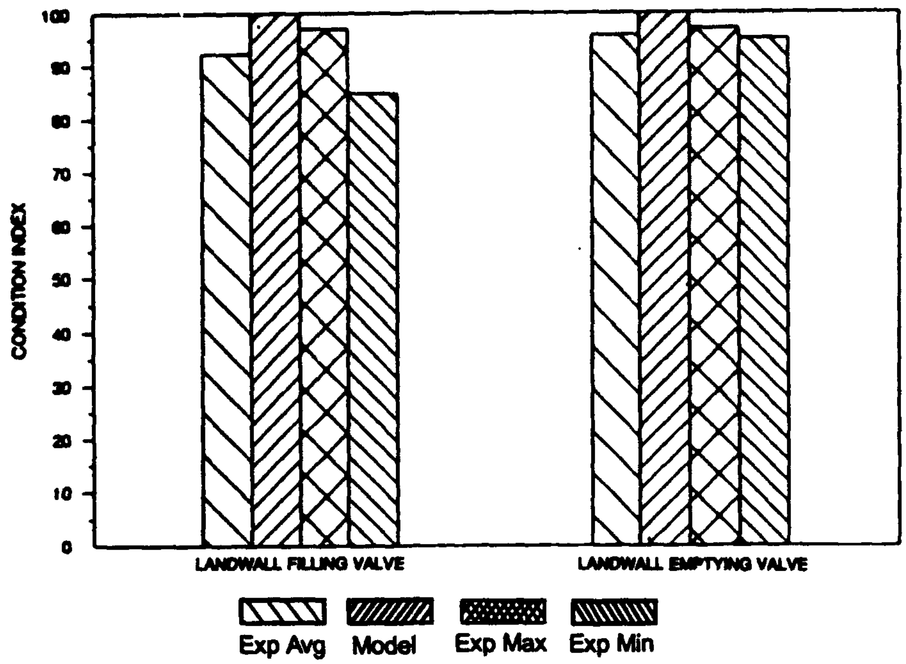

Figure 21. Seal condition

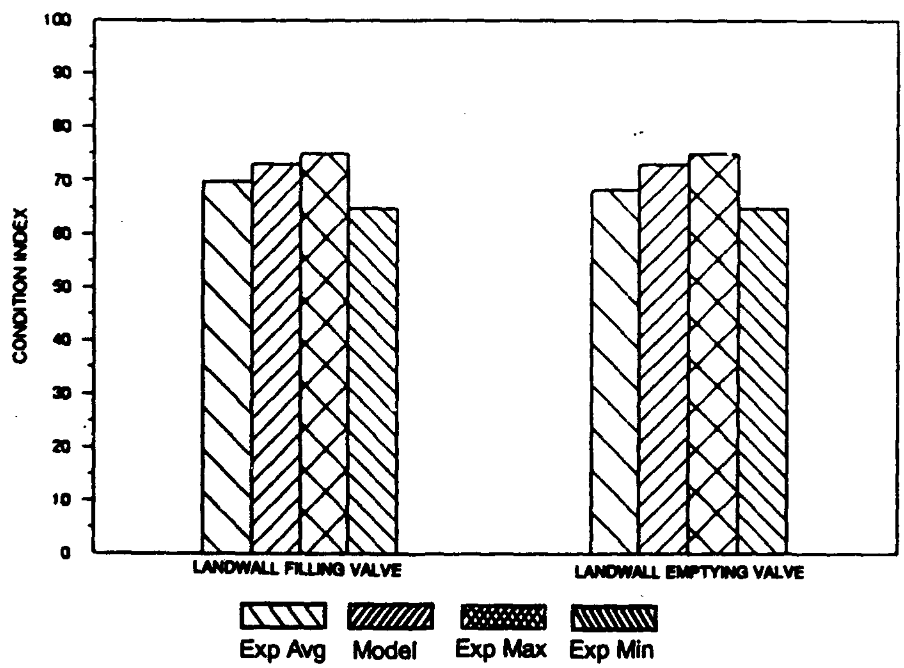

Figure 22. Corrosion

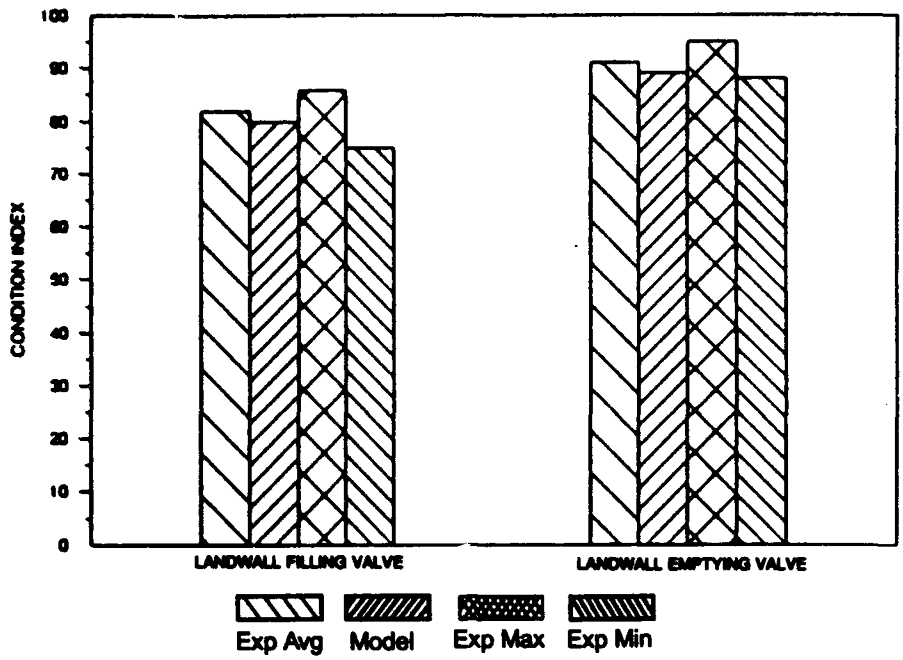

Figure 23. Lifting bracket bushing wear

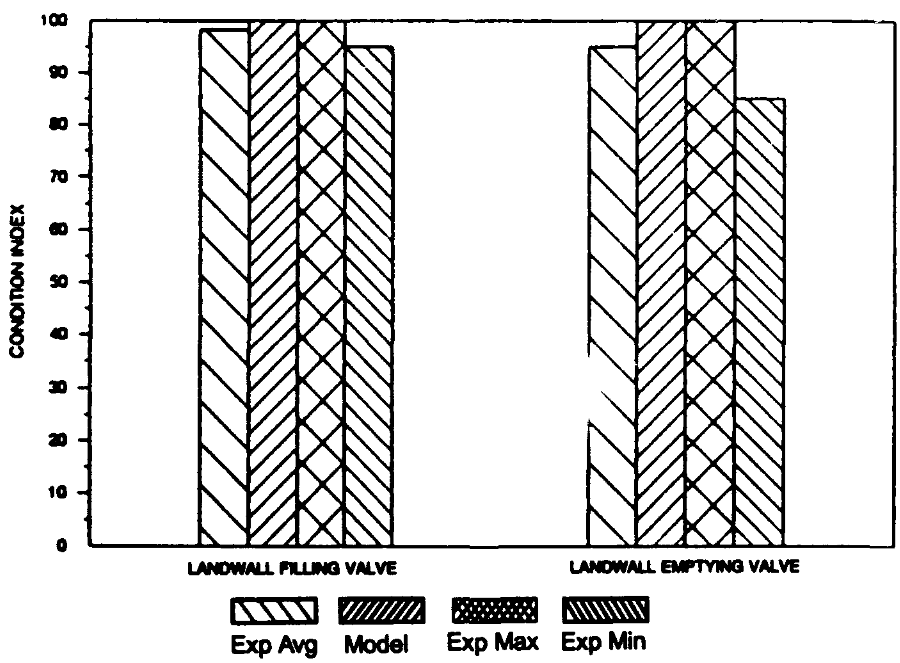

Figure 24. Cracking

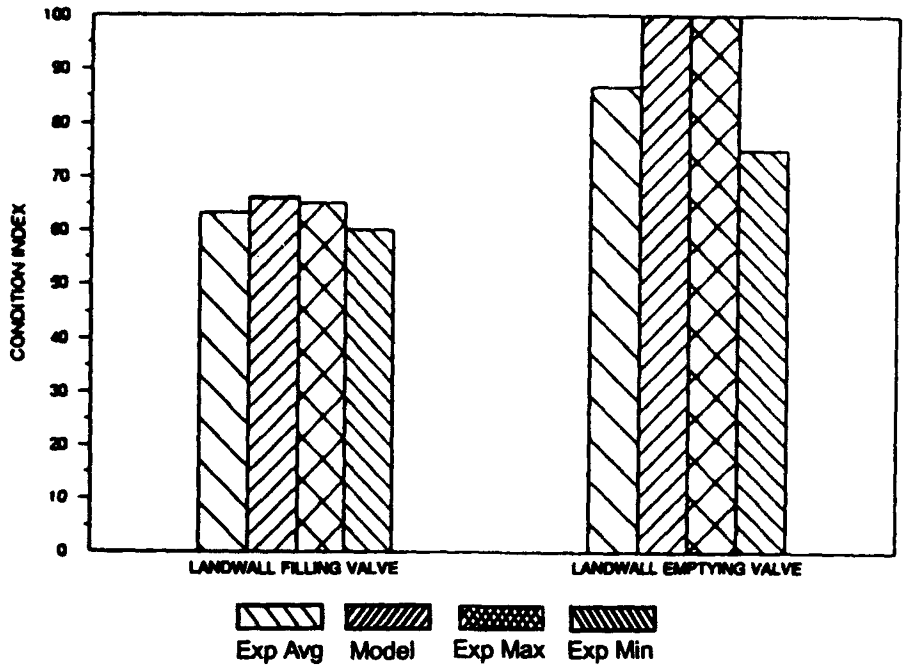

Figure 25. Cavitation/erosion/abrasion

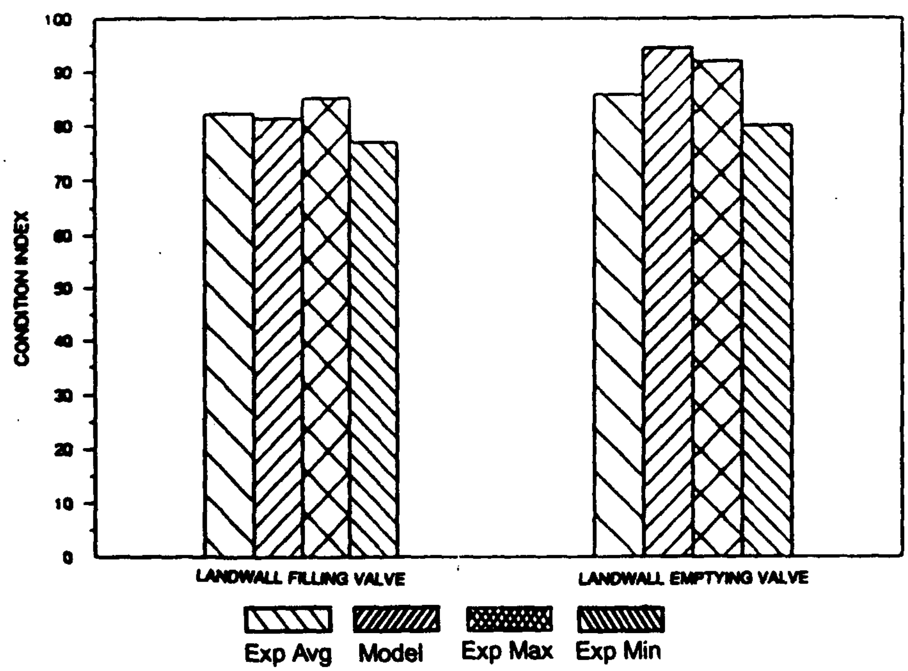

Figure 26. Overall ratings for the valves

return to modify their subjective evaluations to reflect their reduced X_{max}. Therefore, the calculated CI was lower than the expert average.

Trunnion Assembly Wear (Figure 20)

95. The calculated CIs for trunnion wear were consistently higher than the expert average on both valves. Even though these values were high, the experts agreed with the X_{max} and reduction values used in the calculated CIs. A lower X_{max} value may be justified if further field testing on valves with lower condition indexes yields similar observations.

Seal Condition (Figure 21)

96. The calculated CIs describing the seal condition were consistently higher than the expert averages on both valves. The field inspection indicated no damaged or missing seal sections; therefore, the calculated CIs for both valves were 100. Even though no distress information was observed, the experts were reluctant to give the seal condition a perfect rating of 100. This phenomena is consistent with what experts have felt on previous structures (Greimann et al., 1989, 1990, 1991).

Corrosion (Figure 22)

97. The calculated CI values for corrosion on both valves correspond relatively well with the expert averages. The corrosion on both valves was very similar, uniform shallow pitting on the skin and deeper, less dense pitting on the strut arms. The CI was controlled on both valves by the corrosion on the upstream skin. This corrosion was recorded on the inspection form using the percentage area method, Equation 3.25. As a result, the method of recording the number of pits was not tested.

Lifting Bracket Bushing Wear (Figure 23)

98. The calculated CIs for lifting bracket bushing wear approximated the expert values very closely. Field measurements showed wear of 1/16 in. on the filling valve and 1/32 in. on the emptying valve. Both calculated CIs were within two points of the expert averages.

Cracking (Figure 24)

99. Because no cracks were recorded during the field inspection, the calculated CIs were 100. Similar to the seal condition distress, though, the experts rated the valves lower because they did not feel a distress CI could be 100 if the structure was not new.

Cavitation/Erosion/Abrasion (Figure 25)

100. Distinct cavitation damage 1/16 in. deep was observed near the bottom of the downstream skin of the filling valve. The experts rated the cavitation damage low relative to a similar amount of corrosion damage because it increases more quickly than corrosion. As a result, the cavitation rule, which initially had been similar to the corrosion rule, was modified significantly to the form given earlier. The calculated CI for the filling valve with the revised rule was very close to the expert average. Similar to other

distresses, no cavitation damage was recorded for the emptying valve and, therefore, the calculated CI was 100. Nonetheless, the experts were reluctant to give a perfect rating and the calculated CI was approximately 13 points higher than the expert average. Because cavitation only occurs at high lift locations, this distress is not evident on many valves, making calibration more difficult. The rating system for this distress may be modified as more testing is performed.

Overall Valve Ratings (Figure 26)

101. The overall valve ratings from the calculated model tended to track slightly higher than the expert average, primarily because the experts gave low ratings to some distresses even though no distress was observed, for example, cracks and seals. However, both valves did track within five points of the expert averages.

Summary

102. Overall, the calculated CIs tracked relatively well with the expert ratings. Two very good discussion sessions were held with experienced Corps of Engineers experts to develop the framework for the rules and establish X_{max} values. Even though the results were quite encouraging, some uncertainties should be pointed out as the procedure is initially implemented. The initial set of rules will require continual monitoring as the experience level increases.

103. First, even though the expert engineers were very knowledgeable and experienced, three people is a minimum number for calibration. When one of the three gives a much different rating, the average is affected significantly by that individual.

104. Secondly, the valves inspected were generally in very good condition. The expert ratings and the calculated CIs were both quite high. The result is that the rating system was calibrated only for the upper range of the CI scale. A more complete calibration of the CI scale could have been achieved if one of the valves had been in worse condition.

105. Finally, more testing and calibration should be performed. Although a wet tainter inspection has been performed, the CIs were not calibrated in a field test. Butterfly valves have not been tested or calibrated for a wet or dry inspection. However, discussions with the experts have given a high level of confidence to the rules in this part. Looking at the relative importance of valves with respect to the lock structure as a whole, the question remains of how much further testing and calibration is feasible. At this point, it is justifiable to implement the procedure in its current state and allow the rules to evolve as Corps personnel apply them.

PART IV: STRUCTURAL CONSIDERATIONS

106. Many factors were taken into account by the experts as they formulated the CI rules. One of the considerations was subjective safety, which refers to the idea that an engineer using judgment based on experience and/or intuition may decide that a safety problem is likely. A single observation or series of inspection observations may indicate that the potential for a problem exists or that a safety problem is developing and may soon become critical. These types of observations are difficult to quantify because only visual indications of the problems are present. As an example, for tainter valves, excessive movement of the anchorage embedment may indicate a potential safety problem. The embedded anchorage may have corroded and be approaching a failure condition. The only visual observation may be movement at the steel and concrete interface. Only a more detailed inspection, which may require concrete removal, will reveal the true cause. Damaged or loose casting bolts on a tainter valve, and cracks, corrosion, and jumping on tainter and butterfly valves, may also indicate potential safety problems. Deterioration due to these distresses usually is not accounted for in a classical structural analysis technique and cannot be easily quantified.

107. It follows that many structural considerations are embedded in the CI rules in Part III. In addition to functional and operational factors, the experts took structural factors into account when setting limiting values, tolerances, and weight factors. With this in mind, the structural adequacy can be characterized by several of the distress measurements. Some distresses in Tables 2 and 3 have a more significant impact on safety than others. The structural distress subsets are listed in Tables 8 and 9.

108. In an automated CI program being developed for tainter and butterfly valves, an asterisk is indicated on the distress CI calculation if the structural distress measurement exceeds certain bounds.

Level 1 Flag: $55 < CI < 70$

Level 2 Flag: $40 < CI < 55$

Level 3 Flag: $0 < CI < 40$

On the basis of the experts' judgment, the individual distresses are flagged as the CI becomes low. A structural note along with the corresponding measurement will be included in the summary report for potential structural problems that have been flagged. The purpose of the structural notes is to alert the engineer that a potential structural problem may be forming. Values of the measurement X are also included in the notes. For example, for anchorage movement, the three possible notes are:

Level 1 Note--The anchorage movement was measured to be X inches and should be monitored.

Level 2 Note--The anchorage movement was measured to be X inches and could be a problem. Further investigation may be needed.

Level 3 Note--The anchorage movement was measured to be X inches. This is potentially a structural hazard. Further investigation is needed.

Table 8

Tainter Valve Structural Distresses

Structural Distress	Brief Description
Anchorage assembly det.	Embedded steel movement and concrete and steel deterioration
Corrosion:strut arm and bracing material loss	Loss of strut arm and bracing steel
Corrosion:segmental girder material loss	Loss of segmental girder steel
Cracking:strut arms and bracing (dry inspection)	Breaks in strut arms and bracing
Cracking:segmental girder (dry inspection)	Breaks in segmental girder
Jumping (wet inspection)	Abnormal gate jumping

Table 9

Butterfly Valve Structural Distresses

Structural Distress	Brief Description
Corrosion:end plate material loss	Loss of end plate steel
Cracking:end plates (dry inspection)	Breaks in the end plates
Jumping (wet inspection)	Abnormal gate jumping

PART V: SUMMARY AND RECOMMENDATIONS

109. The inspection and rating procedures described in this report have intentionally been kept as simple as possible. The dry and wet inspections require only simple tools such as a tape measure, dial gauge, ruler, and jack. Inspection forms have been developed for tainter and butterfly valves, to record historical information (location, previous inspections, or repair history, etc.) and document distress information (anchorage assembly deterioration, cracking, seal condition, etc.).

110. While the tools and inspection procedures are relatively simple, preparation for a dry or wet inspection is not always as simple. A dry inspection requires dewatering the valve pit, which is expensive, time consuming, and may shut down the lock. A wet inspection involves the use of divers, which is also expensive and requires specialized equipment and planning. A wet inspection is required for all valves. Projection of some data may be possible from historical data if divers cannot measure certain quantities. If the valve rating is sufficiently low from a wet inspection, a dry inspection is necessary, at least of representative valves.

111. Once the data is obtained, a CI is computed directly from the inspection records. The CI is a numbered scale from 0 to 100 that indicates the current state of the structure. It is primarily a planning tool that indicates the relative need to perform REMR work. CIs below 40 indicate that immediate repair may be necessary or possibly that a more detailed inspection and analysis is required.

112. Several distresses reduce the CI according to rules based on the opinion of Corps experts. They involve at least two considerations: (1) serviceability, or how the structure performs its function on a day-to-day basis, and (2) subjective safety, or how, in the judgment of expert engineers, the safety of the structure has been degraded by various distresses. A combined CI for each valve is calculated by weighting each distress. Structural considerations are flagged on the CI list on the basis of subjective safety. A structural note is generated on the summary report for the structural subset of distresses as the CI decreases.

113. The inspection and rating procedure has been applied in two tests (June 1992). The results of these tests have been incorporated into the current version of the procedure.

114. The current inspection and rating procedure for valve structures has had limited testing and should still be considered developmental. As stated in Part III, more extensive testing and calibration of the procedures for tainter and butterfly valves is recommended. Only three experts were used to calibrate the rating process, and because of the relative condition of the valves, only the upper portion of the CI scale was calibrated. However, the

procedures should be exercised to build up the experience level. Modifications to the procedure are certainly expected and suggestions welcomed.

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APPENDIX: MEASUREMENT PROJECTION

1. The concept of measurement projection, as described in Part II, relies on tabulation of historical data. Obviously, when trying to project future response of a system, studying past response provides the most insight.

2. While developing an overall inspection procedure, which integrated a wet inspection into the process, it became clear that trunnion assembly wear measurements could not always be attained by divers. To provide the user with an estimated value for wear in the assembly, wear measurements from previously replaced and rehabilitated valves were tabulated and plotted in Tables A1 and A2.

3. All of the data was gathered from valve maintenance records in the Pittsburgh District. Generally, whenever a valve was replaced or rehabilitated in the Pittsburgh District, outside pin and inside bushing diameters were recorded. Comparing these values with the original design specifications or the as-built conditions, pin and bushing wear was obtained.

4. The pin and bushing wear data for six tainter valves is tabulated in Table A1. The first column in the table identifies the lock facilities and the valves at each location are identified by a four-letter acronym. LW, MW, and RW represent landwall, middlewall, and riverwall, respectively. FV and EV specify whether the structure is a filling or emptying valve. Also, the table identifies the dates the valve was put in and taken out of service. Using these dates, the approximate number of lockages was obtained and listed. Wear on the land and river sides of the valve are listed separately. For pin wear, measurements were recorded at the flange and bevel ends of the pin. Bushing wear was recorded parallel and perpendicular to the concrete.

5. Similar data is listed in Table A2 for twelve butterfly valves. Pin and bushing wear on the land and river sides of the valve are listed separately. In this table, O.V., I.V., O.H., and I.H. refer to measurements taken at the outside vertical, inside vertical, outside horizontal and inside horizontal diameters, respectively, of the pin. Inside measurements were taken near the shoulder and outside measurements were taken near the outside end of the axle. Also, vertical and horizontal bushing wear was recorded. In addition, Table A2 shows the wear of the pin and bushing at the lower strut connection.

6. The maximum of the flange and bevel pin wear for tainter valves was plotted in Figure A1 versus number of lockages. Maximum bushing wear at the parallel and perpendicular diameters was plotted versus the number of lockages in Figure A2. Wear data for land and river sides were plotted in both figures.

7. Figures A3 and A4 are similar plots for axle and bushing wear, respectively, for butterfly valves. Axle wear is characterized by the maximum wear at the O.V., I.V., O.H., and I.H. locations on the axle. The maximum of vertical and horizontal wear characterized the bushing wear plot.

Table A1

Tainter Valve Wear Data

Location	Dates		Number of Lockages	Pin Wear (in.)				Bushing Wear (in.)			
				Land		River		Land		River	
	In	Out		Flange	Bevel	Flange	Bevel	Par.	Perp.	Par.	Perp.
Maxwell	11/64	03/80	123,640					0.050	0.110	0.035	0.060
Pike Island --> LWFV --> LWEV	11/63 11/63	4/88 5/85	107,515 94,381	0.007	0.006	0.007	0.005	0.069 0.010	0.060 0.014	0.042 0.013	0.082 0.020
Hannibal --> LWEV --> RWFV --> MWEV	8/71 8/71 8/71	6/89 4/88 7/80	69,828 69,975 38,062	0.006 0.006 0.005	0.004 0.003 0.005	0.004 0.006 0.004	0.004 0.003 0.004	0.004 0.005 0.009	0.006 0.005 0.020	0.009 0.004 0.007	0.007 0.004 0.013

Table A2

Butterfly Valve Wear Data

Location	Dates		Number of Lockages	Axle Wear (in.)								Bushing Wear (in.)				Wear @ Lower Strut Connection (in.)	
	In	Out		Land				River				Land		River			
				O.V.	I.V.	O.H.	I.H.	O.V.	I.V.	O.H.	I.H.	Ver.	Hor.	Ver.	Hor.	Pin	Bush
Lock #3 A.R.																	
--> LWFV	12/45	03/89	189,600	.034	.028	.024	.020	.039	.032	.019	.014	.030	.032	.036	.041	.180	.049
--> LWEV	12/45	12/89	192,864	.018	.015	.018	.014	.027	.007	.013	.006					.090	.079
--> RWFV	12/57	03/88	166,357	.097	.075	.037	.048	.047	.037	.025	.018					.090	.071
--> RWEV	12/57	12/82	141,283	.012	.012	.044	.044	.014	.014	.041	.041						
Lock #7 A.R.																	
--> RWFV	06/63	09/88	36,811	.020	.015	.010	.005	.019	.015	.010	.002					.375	.029
Lock # 8 A.R.																	
--> RWFV	11/62	09/88	36,518	.016	.013	.016	.009	.041	.034	.021	.014					.240	.045
Lock #4 M.R.																	
--> RWFV	02/63	02/83	226,817	.030	.030	.017	.017	.027	.027	.015	.015						.110
--> LWEV	07/71	12/88	148,661	.065	.050	.089	.070	.062	.050	.080	.059	.005	.113	.019	.092	.012	.029
Lock #7 M.R.																	
--> RWFV	12/66	09/87	161,022	.048	.085	.048	.085							.006	.040	.199	.128
--> RWFV	12/65	05/88	175,264	.059	.056	.047	.016	.059	.056	.076	.066	.035	.076	.112	.162	.500	.858
Lock #8 M.R.																	
--> RWFV	03/77	09/87	72,905	.095	.040	.095	.040	.100	.058	.100	.058	.000	.059	.010	.046	.225	.077
Montgomery O.R.																	
--> LWFV	05/71	06/84	255,735	.045	.028	.003	.003	.029	.023	.003	.003					.125	.015

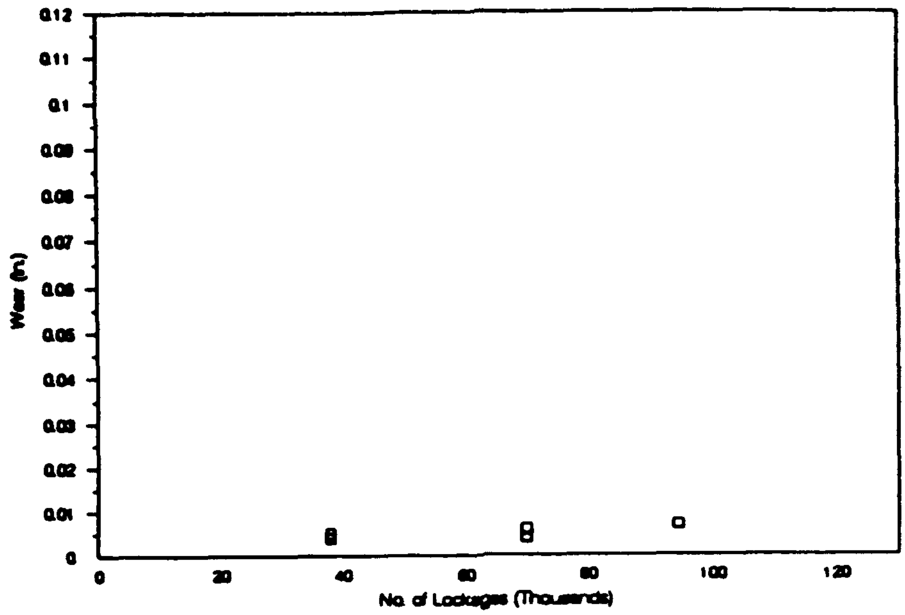

Figure A1. Tainter valve pin wear

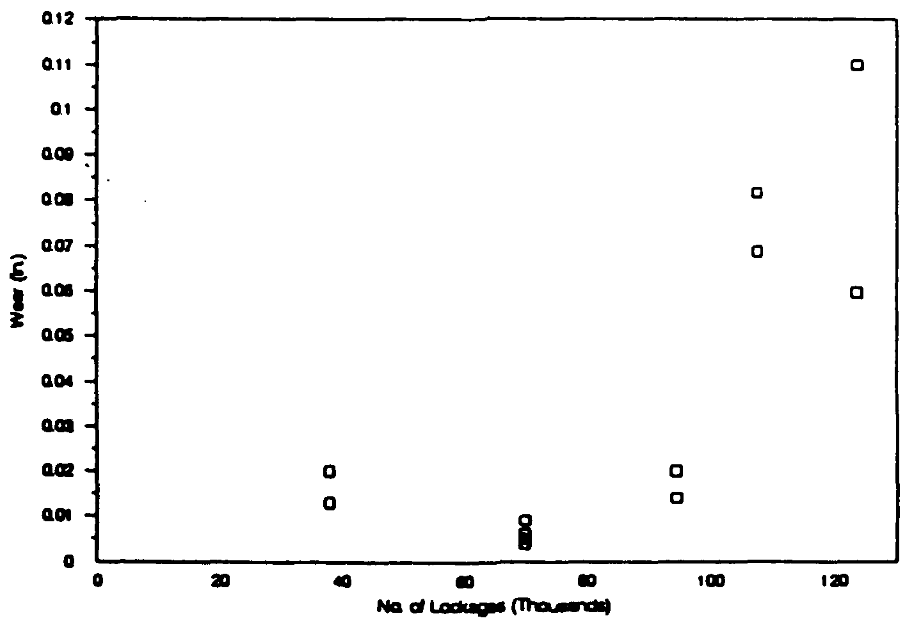

Figure A2. Tainter valve bushing wear

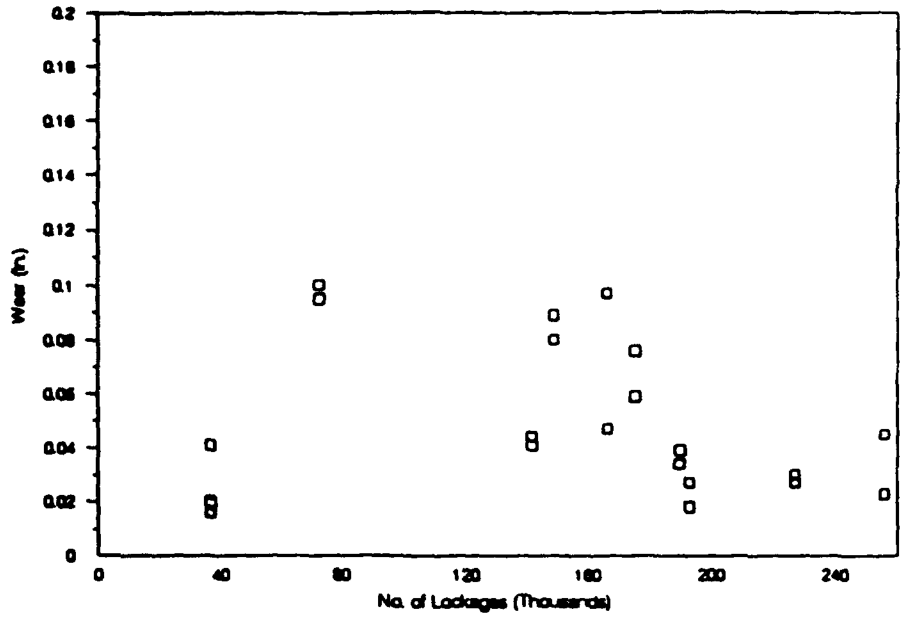

Figure A3. Butterfly valve axle wear

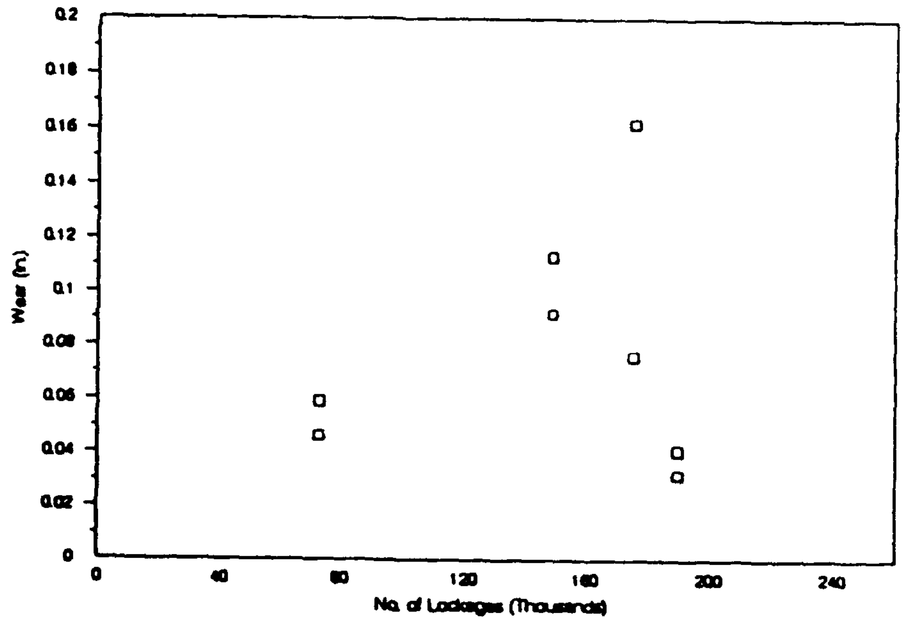

Figure A4. Butterfly valve bushing wear

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