WATER OPERATION AND MAINTENANCE BULLETIN

No. 194 December 2000

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UNITED STATES DEPARTMENT OF THE INTERIOR Bureau of Reclamation

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This *Water Operation and Maintenance Bulletin* is published quarterly for the benefit of water supply system operators. Its principal purpose is to serve as a medium to exchange information for use by Bureau of Reclamation personnel and water user groups in operating and maintaining project facilities.

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***Cover photograph*:** Failed gate No. 2. Note that the arms have fallen off the concrete corbel support.

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DAM DRAIN CLEANING – SUCCESSES AND FAILURES

by William R. Fiedler, Civil Engineer, Bureau of Reclamation, and
Gary Turlington, Geologist, Bureau of Reclamation

Introduction

Drains associated with dams are important features of a design. Drains are used to control seepage, reduce uplift pressures acting on structures, and reduce the water levels within embankments and slopes. Thus, effectively functioning drains are often critical to the stability of dams and associated features. Drains can become plugged, and their effectiveness can be reduced, through a variety of mechanisms. In order to re-establish the effectiveness of drains that have become plugged, or partially plugged, a number of cleaning methods can be used.

The Bureau of Reclamation (Reclamation) is in the process of preparing a manual on drains associated with dams. The manual will provide background information on a variety of drain applications as well as information on maintaining drains. Chapters in the manual will cover the following topics: drain systems, drain design and analysis, drain installation methods, drain performance, and maintaining drains. The chapter on drain performance will provide case histories of drains that have become plugged and the cleaning systems used to rehabilitate them. The chapter on maintaining drains will address plugging mechanisms, methods for evaluating drain effectiveness, criteria for drain maintenance, and drain cleaning methods.

A draft of the manual is being completed for final review. The manual will then be updated, printed, and distributed. It is anticipated that the manual will be available in May 2001. This paper presents some of the information that will be included in the manual—plugging mechanisms, drain cleaning methods, four illustrative case histories, and guidance on how to conduct an efficient drain cleaning program.

Plugging of Dam Drains

Drains can be plugged through a variety of mechanisms, including calcium carbonate deposits, bacterial deposits, and the settlement of fines or sand particles. The following is a summary of the different plugging mechanisms.

Calcium Carbonate

Calcium carbonate (calcite) is often found at the emergence of seepage water into or from foundation drains. The following equations describe the formation of calcite from water in contact with concrete or grout from foundation treatment. The equations are listed in their simplest forms. The chemical equations for calcite formation are:

$$Ca(OH)_2 + 2CO_2 \text{ ------ } Ca(HCO_3)_2 \qquad (1a)$$

$$Ca(OH)_2 + Ca(HCO_3)_2 \text{ ------ } 2CaCO_3 \text{ (calcite)} + 2H_2O \qquad (1b)$$

In equation 1a, calcium bicarbonate [$Ca(HCO_3)_2$] is formed when carbon dioxide from air reacts with calcium hydroxide [$Ca(OH)_2$] from concrete, grout, or certain foundation rocks such as limestone. In equation 1b, calcium bicarbonate—which is incompatible in solution with calcium hydroxide—further reacts to precipitate calcium carbonate. In equations 1a and 1b, the reactants are usually present in seepage from concrete structures, a foundation grout curtain, or foundation rocks like limestone. Precipitated calcium carbonate forms a white solid deposit. These solids may mineralize and harden with time.

Bacterial Deposits

Bacterial deposits result from life process activities of certain bacteria which obtain energy for their existence from the conversion of sulfates to sulfides, iron to ferric oxides, and manganese to manganese oxides. Bacterial deposits are common and can develop under a variety of conditions. Bacterial growth can occur anaerobically (without oxygen) or aerobically (with oxygen). Energy sources can be organic materials or other carbon-containing substances. Bacteria require a steady supply of dissolved iron, manganese, or sulfate, depending on the type of bacteria. Most of the time, bacterial deposits are soft and easily removed, but some can become hard and mineralized.

Settlement of Fines or Sands

The settlement of fines or sand particles can also reduce the effectiveness of drains. The source of fines or sand particles can be foundation or embankment materials in an embankment dam (which would cause a greater concern regarding the potential for piping of embankment materials).

Cleaning Methods

Depending on accessibility to drains, the type of plugging mechanism, and the application of a given method, success in re-establishing drain flows may vary from site to site. Several methods have been successfully used by Reclamation to clean plugged drains and restore their efficiency. The methods are listed below.

Rodding

A steel rod or similar device is used to break through a plugged encrustation deposit. In some cases, a metal object, such as a star drill, has been attached to a line and dropped down the foundation drain to break through the blockage. Flushing of the hole is usually performed after rodding. Rodding does not completely clean the drain hole walls; it is most effective where plugs high in the drains must be removed but where lower areas of the drain still allow good flow through the drain hole walls. This is an economical method that uses simple equipment.

Flushing and Air Lifting

Soft and loose deposits can be flushed out of drain holes by placing the end of a water line at the bottom of a drain and using water pressures of up to 250 pounds per square inch (lb/in^2) and flows up to 60 gallons per minute (gpm) to loosen the deposits and flush them out of the hole. Air lifting is done in a similar manner, but it uses compressed air to force debris out of the drain.

Reaming, Overcoring, or Drilling of New Holes

For foundation drains in rock, the existing drain holes can be reamed up to the original diameter using a drill to remove obstructions and coatings on the borehole walls. Correct alignment of the drill and drill bit is critical to successfully using this method.

Overcoring is another method that uses drill equipment to restore the efficiency of drains. For foundation drains in rock, the existing drain holes are redrilled to enlarge the original diameter of the hole by 1/4 to 1 inch. The first cleaning using overcoring appears to achieve the most improvement in drain efficiency. Subsequent redrilling of the same hole does not result in the same improvement.

As an alternative, new holes are sometimes drilled to replace the old ones, if the desired efficiency cannot be economically achieved with overcoring or reaming. All the drilling methods are usually very effective in improving drain efficiency, but these methods are some of the more costly methods of drain rehabilitation.

Rotary Tube Cleaners or Mechanical Abraders

This method cleans the deposits from the inside surfaces of the foundation drain, restoring the original diameter of the hole. These devices typically have a rotating cutting head on the end of a flexible rod or hose. A Roto-Rooter device, a common commercial method for cleaning sewer drains, is a device in this category that has been successfully used in foundation drain holes.

Ultrahigh Pressure Water Jet System

A typical ultrahigh pressure water cleaning system delivers a flow of 3 to 10 gallons per minute at pressures between 20,000 and 50,000 lb/in^2. A high-pressure pump is set above ground and connected to a filtered water supply. Hoses are provided from the pipe to the hole being cleaned, and a tripod is used to lower the equipment in and out of the hole. A jetted nozzle is attached to a flexible lance, and the unit is lowered into the hole and removed slowly during the cleaning operation. Typically, a number of different heads with different nozzles can be used.

High-Pressure Water Jet System

This method delivers a flow of 10 to 20 gallons per minute at a pressure typically between 6,000 and 10,000 lb/in^2. Other than the pressure and flow rates, the equipment and methods for these systems are similar to the ultrahigh pressure water jet systems. Figure 1 shows equipment used for high-pressure water jet cleaning.

Figure 1.—High-pressure water jet cleaning of foundation drains.

Chemical Treatments

Sulfamic, sulfuric, and hydrochloric acids have been used to dissolve deposits in drains. Sulfamic acid has been field tested to chemically dissolve calcium carbonate in clogged foundation drains. Granular and pelletized forms of the acid are applied to drains in quantities equivalent to 2 to 8 percent of the unobstructed volume. Other acids have been used in liquid form with limited success because of dilution and health problems related to their use. Acids have not been effective in clearing fully plugged drains. Acids seem most effective when used as a maintenance procedure for controlling the buildup of deposits in drains.

Relief wells downstream of Grand Coulee Dam have been successfully maintained, and major plugging of the wells has been avoided through the use of both bleach and sulfamic acid. The solutions are alternated in the wells, and the rapid change in pH has been effective in controlling bacterial deposits.

Another chemical method that has been used is adding carbon dioxide under pressure to drains plugged with calcium carbonate. This process has the potential for dissolving calcium carbonate since the carbon dioxide can acidify water in the drain. Typically, the zone being treated is isolated with packers. An attempt to use this method at Folsom Dam was unsuccessful because joints in the foundation rock made it impossible to pressurize the holes.

Case Histories

Four case histories are provided to illustrate some of the plugging mechanisms that can affect drains and to illustrate cleaning methods—some that were successful and others that were not.

Case History No. 1 – Friant Dam

Introduction.—Friant Dam was constructed in 1942. Friant Dam is a Reclamation concrete gravity dam located approximately 25 miles northeast of Fresno, California, on the San Joaquin River. The dam has a structural height of 319 feet and a crest length of about 3,500 feet. Formed drains within the dam, as well as foundation drains, are provided at Friant Dam to relieve uplift pressures. Five-inch- diameter foundation drains at 10-foot centers are provided with depths into the foundation from 12 to 100 feet. The foundation drains discharge into the grouting and drainage gallery, which is located in the lower portion of the dam. Seepage is collected from blocks 21-28, 29-34, 34-49 and 49-57. A V-notch weir is used to measure the flow in the drainage channel at each of the four collection points.

The foundation drains had become plugged with calcium carbonate, as indicated by reduced depths that a probe could be inserted into the drain holes and by increased measured uplift pressures within the dam foundation. Four lines (oriented in the up-stream/downstream direction, 5 to 6 pressure pipes per line) of uplift pressure pipes were provided to monitor foundation pressures at the base of the dam. Only one of the lines (line 4) was responsive to changes in the reservoir elevation, and this line indicated uplift pressures greater than the assumed design uplift pressures. Figure 2 shows the locations of the line 4 uplift pressure pipes. Uplift pressure pipe A is located upstream of the foundation drain holes, and the remaining uplift pressure pipes are located downstream of the foundation drain holes.

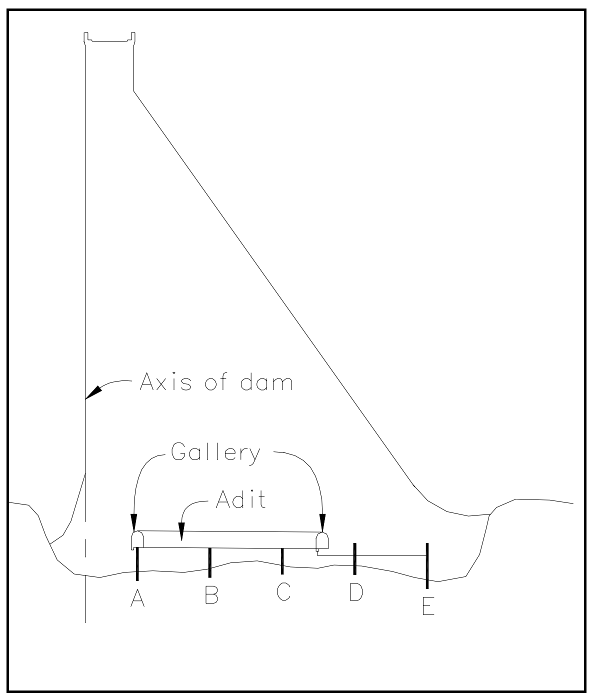

Figure 2.—Friant Dam, uplift pressure pipes (line 4, Sta. 24+55).

Drain Cleaning Operations .—In 1993, a contract was issued to clean the foundation drains in blocks 47 through 54 using high-pressure water jetting techniques. Results of the cleaning effort (pressures up to 10,000 lb/in^2 were used) indicated that most of the drain holes were opened to greater depths and that there was a decrease in pressure gauge readings for line 4 after cleaning.

In December 1997, the foundation drains were cleaned again using high-pressure water jetting. One hundred ninety eight drains were cleaned in blocks 27 through 65. A 4-inch-diameter plumb bob was passed through each drain before and after cleaning to confirm that an acceptable degree of cleaning had been accomplished. In addition, uplift pressures along line 4 were recorded before and after drain cleaning.

A hydroblast pump (20,000 lb/in^2 at 17 gpm) was used as the power unit for the drain cleaning operations. The cleaning tool was a speed-governed reaction-jet rotating mole with a proprietary head design. The mole, with its rotating head and diverging nozzles, is capable of cutting through solid blockages and scrubbing the walls clean at the same time. A portable derrick and electric winch was used to control the raising and lowering of the mole within the drain holes. A 4-inch centralizing cable support system was also provided for the mole.

The results indicated that the drain cleaning was successful. Prior to cleaning the foundation drains, very little water was flowing in the drainage channels of the drainage gallery. After cleaning, water was flowing at a much higher rate through the channels (based on a visual assessment). Pressures were recorded at the uplift pressure pipes in Line 4 before and after the cleaning. The following table summarizes the readings, which indicate the cleaning was very effective in reducing uplift pressures, at least in the portion of the dam foundation near line 4.

Location		Pressure head (feet) December 9, 1997	Pressure head (feet) January 2, 1998
Line 4 Station 24 + 55 Block 49	A	52	48
	B	26	10
	C	36	2
	D	23	3
	E	40	3

Hole depths before and after the drain cleaning indicated that the hole depths increased for all but one foundation drain hole (block 58, drain No. 3). The following table provides the hole depths before and after cleaning for selected drain holes, indicating that the drain cleaning was effective.

Block number	Drain number	Depth before cleaning (feet)	Depth after cleaning (feet)
32us	5	37	90
33us	1	49	90
33us	5	55	86
35us	2	66	83
39us	4	18	73
39us	6	29	84
43us	2	36	86
45us	4	60	89
48us	4	67	90
48us	5	67	94
50	1	13	71
50	2	12	71
58	2	37	80

Although the uplift pressure data are only at one location in the dam foundation, other evidence, including increased depth of probed holes and visual indication of increased seepage, indicates that the cleaning was effective in increasing the efficiency of the drains across the dam foundation.

Case History No. 2 – Upper Stillwater Dam

Introduction.—Upper Stillwater Dam was constructed in 1987. Upper Stillwater Dam is a Reclamation roller-compacted concrete gravity dam located 31 miles northwest of Duchesne, Utah. The dam has a structural height of 292 feet and a crest length of about 2650 feet. Foundation drains are provided at 10-foot centers and at least 75 feet into the dam foundation. During first filling of the reservoir, flowing sand from some of the drains and filling of some of the drains with sand (which reduced the effectiveness of the drains) was noted.

Slotted polyvinyl chloride (PVC) pipe wrapped in filter cloth was installed in some of the drains to filter the migrating sand. Most of the filter-wrapped drains plugged completely because of the presence of iron-fixing bacteria; therefore, the installation of the filters was discontinued. Tests indicated that the plugging of the filter fabric typically occurred in a few hours.

The sources of the sand are backfill material placed at the upstream heel of the dam and sand-filled joints in the dam foundation. Concern over clogged drains was that the factor of safety for sliding on shallow beds would be reduced, and washing of sand from foundation joints in large quantities could lead to settlement, cracking, and ongoing maintenance problems for the dam.

Remedial Measures.—In 1992 and 1993, remedial action was undertaken to address the migration of sand into the drains. A limited grouting and drainage program was initially planned, but the program was expanded to include grouting and drain remediation across the entire foundation because of the high grout takes that occurred at the start of the program. The treatment from the gallery included upstream grouting, redrilling the downstream drains, and installing drain pipe (some surrounded by a filter pack).

The rate and distribution of sand infiltration into the drains and the drain flows were drastically reduced by the grouting program. Probe data of the drain holes from 1993 indicated a definite reduction in sand infiltration rates with the reservoir at maximum elevation. In a 1995 report [4], caution was urged over installing 1- or 1-1/2-inch slotted PVC pipe in the 4-inch drains until it could be proven that the iron bacteria problem had been eliminated and that there was no need for filter installation. Iron bacteria was not a problem in the 4-inch open drains because the drains could be readily cleaned.

Case History No. 3

Introduction.—Case History No. 3 involved a concrete gravity dam located in the Pacific Northwest that is owned and operated by an agency other than Reclamation. The dam is 256 feet high and 3,791 feet long. Bedrock at the dam is hard basalt. The basalt is comprised of a successive series of basalt flows separated by thin (several inches to several feet thick) interlayers of volcanic ash and tuff. The ash and tuff layers are typically hard, being baked by deposition of the overlying basalt flow.

The dam was constructed in 1969. Five hundred and forty foundation drains were drilled to 80-foot depths to provide seepage paths to relieve uplift pressures that may develop under the dam and potentially cause stability problems. Since construction of the dam, the foundation drains experienced gradual loss of effectiveness, inducing increased uplift pressures.

Drain Cleaning Operations.—Foundation drains in the dam had reduced flows, causing increased uplift pressures that caused concern for static and dynamic stability of the structure. The drains became plugged with calcium carbonate and silt that entered through fractures that intersect the drain holes in the basalt bedrock. Since there is no natural, geologically occurring source of calcium carbonate in the area, the source of the calcium carbonate was believed to be the concrete dam. The source of the silt was sedimentation in the reservoir.

In 1992, conventional drilling methods were used to clean the silt and calcium carbonate from the foundation drains. The boreholes were reamed using diamond drilling to clean the borehole walls, increasing the borehole size by an additional 3/32 inch.

Figure 3 shows the immediate and significant response to the drain cleaning operation. Measured uplift pressures were immediately reduced by 50 feet of pressure. Figure 3 also

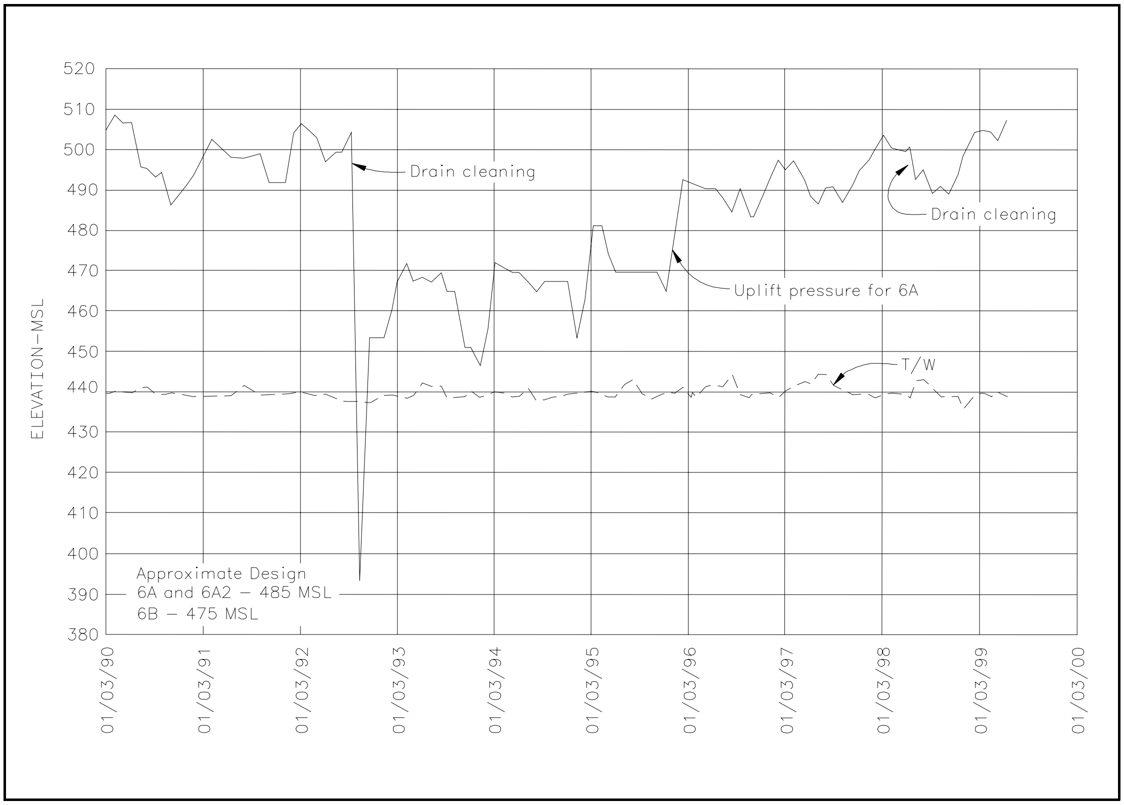

Figure 3.—Uplift pressure response to drain cleaning.

shows a gradual resumption between mid 1992 and 1998 of decreased effectiveness of the foundation drains until uplift pressures nearly returned to pre-cleaning levels.

In 1998, a contract was issued for drain cleaning of the same drains using high-pressure water jet methods. The contract allowed the contractor to determine the pressure and nozzle configuration needed for the cleaning operation. High pressures of 12,000 to 13,000 lb/in^2 and low flow rates of 15 gpm were used.

Figure 3 shows the fluid jet method was marginally successful in increasing drain flows and reducing uplift pressures. Uplift pressures were reduced by only 5 to 7 feet, and within several months, uplift pressures returned to pre-cleaning levels.

Conclusions.—Some of the conclusions reached regarding the cleaning methods are:

(1) The use of conventional drilling methods in 1992 to clean the drain holes was effective.

(2) The conventional drilling action may also have broken and removed calcium carbonate for a short distance into the fractures that intersect the borehole, removing blockages in the seepage path and enhancing flow into the boreholes.

(3) The use of high-pressure fluid jet methods in 1998 to clean the drain holes was marginally effective. Some possible reasons for the limited effectiveness are:

   (a) Insufficient pressure may have been applied to induce scouring/etching of the calcium carbonate from the borehole walls.

   (b) The water jet may have been raised within the borehole too rapidly to induce scouring/etching of the calcium carbonate on the borehole walls.

   (c) The water jet nozzles were not properly oriented and/or sized to induce scouring/etching of the calcium carbonate on the borehole walls.

Case History No. 4 – Folsom Dam

Introduction.—Folsom Dam is a Reclamation structure located on the American River in the Central Valley of California about 20 miles northeast of Sacramento. Folsom Dam consists of a concrete gravity section across the river channel flanked by earth wing dams extending from the concrete section to high ground on either side of the river. Bedrock at Folsom Dam is quartz diorite, a hard granite-like rock.

Folsom Dam was constructed in 1956. Three-inch-diameter foundation drains were drilled on 10-foot spacing to provide seepage paths to relieve uplift pressures that could develop under the dam and potentially cause stability problems. Since construction of the dam, the foundation drains experienced gradual loss of effectiveness, inducing increased uplift pressures.

Drain Cleaning Operations.— In 1978, the foundation drains at Folsom Dam showed signs of normal seepage. By 1980, the examination report suggested that the foundation drain and discharge pipes be probed and cleaned where plugged, and efforts to probe and clean the foundation drains were initiated. The 1983 examination report stated that work on the drain probing and cleaning recommendation was incomplete but that partial work had been done and would continue until finished. Drain cleaning efforts continued at Folsom Dam with the chronology of drain cleaning events listed below.

1 – High-Pressure Fluid Jet Methodology.—The Industrial Hydropower Company of Placerville, California, (Industrial Hydropower) volunteered to demonstrate their high-pressure water-blasting system on the 3-1/2-inch diameter drain holes at Folsom Dam in April 1983. They demonstrated its effectiveness by removing some exposed hard calcium carbonate.

In May 1983, Industrial Hydropower returned to Folsom Dam for a more extensive demonstration, cleaning two drain holes selected by Reclamation. Each of the holes was inspected before and after the demonstration with a borehole camera. The demonstrations showed that this equipment can access tens of feet into drain holes and is capable of removing hard calcium carbonate deposits.

2 – Chemical Removal of Carbonate Deposits.—In 1985, Reclamation studied the potential for chemical removal of hard, thick calcium carbonate deposits that had reduced casing and drain hole diameters. Granular and pelletized forms of sulfumic acid were applied to a sampling of drains in quantities equivalent to 2 to 8 percent of the unobstructed drain volumes. An immediate vigorous reaction was observed at the drain opening when the granular form of the acid reached the point of obstruction. (Obstructions near the upper ends of the drains were detected by probing.) The pellets dissolved slowly, providing acidification at the bottom of the hole over an extended period.

Followup inspection of the drains indicated no evidence of improvement in drain function. An odor was detected in and around the treated areas and, because of concern for safety of personnel, acid treatments were discontinued. It was concluded that possibilities for the sulfumic acid treatment to dissolve the calcium carbonate obstruction remain, and the problem of generated gases needs to be studied. In addition, environmental issues of introducing acid into the groundwater table may preclude the use of acid treatment. The sulfumic acid treatment may be best used as a deterrent to calcium carbonate buildup on a preventative maintenance basis.

3 – Ultrahigh Pressure Fluid Jet Methodology.—In 1987, Power Master, Inc., demonstrated an ultrahigh pressure water jet method of cleaning the foundation drains at Folsom Dam. The contractor, using a flow rate of 0.6 gallon per minute and nozzle configurations of 45°, 30°, and 20°, had little success penetrating a hard calcium carbonate plug located at a depth of 35 feet. The contractor also tried a nozzle tip with jets designed to cut through the center of the plug. This tip also failed to show satisfactory success. The contractor then increased discharge pressure to an estimated 36,000 lb/in^2 with a 60° nozzle tip. This tip cut through approximately 6 feet of the calcium carbonate plug. A borehole camera lowered into the drains showed satisfactory cleaning.

The equipment used to clean the foundation drain holes required a 440-volt power source that was very bulky, hard to maneuver, and prone to breakdown. It was concluded that modifications to the 1987 vintage equipment would be required to adapt the ultrahigh pressure cleaning equipment to clean foundation drains.

4 – Roto-Rooter.—In 1987, a local Roto-Rooter franchise demonstrated the use of an electrically driven, rotary, interior pipe cleaner to break though a plugged foundation drain using a variety of cutting edges. The drain hole was plugged from 16- to 25- and 40- to 50-foot-depths. The borehole was opened to 129 feet in 6 to 7 hours. The flow rate from the drain hole increased from no flow to 1.6 gallons per hour. The foundation drain hole was inspected with a borehole camera and found to be free of calcium carbonate.

5 – High-Pressure Fluid Jet Methodology.—In 1988, Donco Industries, Inc., demonstrated high-pressure fluid jet methods. The equipment was most effective at a working pressure of 10,000 lb/in^2 and a flow rate of 20 gpm. System pressure losses were 150 lb/in^2 pressure per 50 feet of 1/2-inch-I.D. supply hose and a loss of 3,300 lb/in^2 pressure for 25 feet of 1/4-inch-I.D. flexible, nylon steel, lance hose. The heads available for use were:

(a) Seven-sixteenths-inch flexible lance, with 25 feet of 1/4-inch-I.D. nylon steel hose, with one hole straight forward and 18 holes pointing forward 30^o

(b) One-half-inch molehead, with 5-foot-long, 1/2-inch-I.D. steel shaft, and one hole straight forward, three holes at 45^o forward, and three holes at 35^o aft

(c) Two-inch molehead, with 5-foot-long, 1/2-inch-I.D. steel shaft, and several different nozzles that could be arranged as needed

(d) Two-and-one-half-inch rotating molehead, with 5-foot-long, 1/2-inch-I.D. steel shaft, one hole straight forward, two holes at 45^o forward, and two holes at 45^o aft

A 1/2-inch-I.D., 30,000 lb/in^2 capacity hose was used to convey flow from the pump. As a safety feature, a dump-load device with a foot pedal was used to regulate pressure to the molehead or lance.

In drain hole 12-D-4, a solid calcium carbonate plug was encountered from 50 to 80 feet and cleaning was continued to 130 feet. After cleaning, the drain hole was flushed with water. Inspection with a borehole camera showed approximately 60 percent of the borehole circumference was clean. The contractor then used the 2-1/2-inch rotating molehead to reclean from 50 to 60 feet in 5 minutes. A recheck with the borehole camera showed no significant change.

The contractor then used the 2-inch-diameter molehead to reclean from 50 to 60 feet. A recheck with the borehole camera at 55 feet where the cleaning was concentrated, showed calcium carbonate on 30 to 40 percent of the borehole wall. The other 60 to 70 percent of the borehole wall was clean.

In drain hole 12-D-5, a solid calcium carbonate plug was encountered at 14 feet. Using the flexible lance, the contractor attempted to cut through the plug for 5 minutes with no success. An attempt to break through the plug with the 2-1/2-inch rotating molehead was also unsuccessful. The contractor switched to the 1/2-inch molehead and penetrated the plug in a few minutes; the plug was only a few feet in length. The contractor then used the flexible lance to clean the drain hole from 17 to 140 feet in 17 minutes. During cleaning of drain hole 12-D-5, the contractor did not rotate the lance. The borehole was then inspected with the borehole camera. Streaks were present, indicating that the lance should be rotated to ensure complete removal of deposits.

Drain Cleaning Program

In order to conduct an effective drain cleaning program, monitoring of key parameters before and after the cleaning should be conducted. The following is a checklist of recommended procedures for ensuring a successful drain cleaning program.

(1) Measure drain flows prior to cleaning—measuring individual drains if possible.

(2) Take uplift pressure readings and piezometer readings prior to cleaning.

(3) Probe holes with rods or a plumb bob to determine depth/length of drain prior to cleaning. Compare this measurement to as-built depths, if available.

(4) Use a borehole camera to inspect drain walls prior to cleaning. Note changes in rock type, deposits, and other variables along length of hole. The borehole may require washing/flushing to allow access with the borehole camera or to provide a clean column of water for viewing with the borehole camera.

(5) Initiate cleaning of the holes. If using water jetting methods, record nozzle details, nozzle orientations, cleaning rate (feet per minute), and pressures used during cleaning. Also, document specifics of equipment used (catalog sheets and devices used to centralize the nozzles in the hole, etc.).

(6) Flush holes thoroughly with water after cleaning.

(7) Probe holes with rods or plumb bob to determine depth/length of drain after cleaning. Compare this measurement to as-built depths (if available).

(8) Use a borehole camera to videotape drain walls after cleaning. Note any remaining deposits or partial plugs along depth of hole as well as any evidence of erosion or caving of sidewalls from cleaning. If deposits still remain, additional cleaning efforts should be considered. If possible, determine if deposits were cleaned from fractures/joints intersecting the borehole walls.

(9) Measure drain flows after cleaning—measuring individual drains if possible.

(10) Take uplift pressure readings and piezometer readings after cleaning.

(11) Summarize cleaning activities in a report, including graphs and tables that readily portray before and after conditions and demonstrate effectiveness of cleaning. Integrate after cleaning flow rates and/or uplift pressures and piezometer readings with historical instrumentation records for the structure. See figure 3 as an example.

Conclusions

Drains associated with dams can become plugged through a number of different mechanisms, including calcium carbonate deposits, bacterial deposits, and settlement of fines or sands. Drain cleaning methods include rodding; flushing and air lifting; reaming, overcoring, and drilling new drains; rotary tube cleaners or mechanical abraders; high-pressure; ultrahigh pressure water jetting; and chemical treatments. The effectiveness of a given cleaning method will vary with the type of deposit and other factors. An appropriate cleaning method must be chosen for a given plugged condition. Finally, in order to ensure a successful cleaning program, monitoring of key parameters should be performed before and after a cleaning program to evaluate the effectiveness of the cleaning.

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FENCE CROSSINGS AT CANALS

by Jay Chamberlin[1] and Dave Nelson[2]

Fences must frequently cross canals to keep livestock "fenced in" when the canal is dry. Some crossings are rebuilt each fall when the canal is drained and then removed again before the canal starts delivering water in the spring. At times, some type of dangling or floating "fence" is constructed, which does a poor job of keeping cattle in when the canal is drained, and which catches debris when the canal is flowing.

To reduce this perennial problem, East Bench Irrigation District in Montana developed a suspended gate system which can be raised above the canal water level during the irrigation season and then lowered to the base of the canal when it is drained. This system has been used successfully in the district for 6 years.

Photo 1

Photo 1 shows the gates in the lowered position (dry canal). In this position, the gates are held upright in place by a permanent post and cable suspension system, built with 3/8-inch diameter cable. This suspension system is visible in photo 2. There is a horizontal suspension cable with vertical cables reaching to the two top corners of each gate. Chains (with an appropriate amount of slack) can be used to link the gates on the side or at the bottom.

A second horizontal cable line is strung through eyelets at the two top corners of the middle gate (photos 3 and 4). One end of this cable is firmly attached to the mounting post on one side of the canal. On the other side of the canal, the cable can be tightened or loosened with a winch or pickup truck to raise or lower the gates. The cable slides freely through the gate eyelets as it is tightened or loosened.

Photo 2

[1] Manager, East Bench Irrigation District, 1100 Highway 41, Dillon, Montana 59725.

[2] Engineer, Bureau of Reclamation, Billings, Montana 59107-6900.

Photo 3

Photo 4

In the raised position (photo 4), the cable can be locked in place (photo 5) during the irrigation season. Raising or lowering the gates takes about 10 minutes.

Photo 5

The mounting posts at the ends must be built strong to handle the constant tension of the cables. They must be high enough to suspend the gates above the canal water (remember to allow for sag in the horizontal cables, which may be 3 to 4 feet or more). The gates used are typical farm livestock gates. Gate ends are modified as necessary so their length and angles fit the canal prism when lowered (as visible where the two gates meet in photo 1).

Gate materials are purchased from local suppliers, and the gate sections are prefabricated to the appropriate dimensions in the district's shop (a good winter project). Field installation typically takes two employees 2 or 3 days. The cost for labor and materials is usually around $800 or less. During the 6 years the gates have been in use, little maintenance has been needed.

BOLLARD INSTALLATION AT SIMS POND DAM

by Tom Brown, Civil Engineer, P.E., Bureau of Reclamation

Sims Pond Dam is located in the National Park Service (NPS) Blue Ridge Parkway (Parkway) near Blowing Rock, North Carolina. Even though the dam was constructed by private concerns prior to the completion of the Parkway, both the dam and reservoir are now an integral part of it. There is a turnout/overlook from the Parkway at the dam, and a hiking trail starts at the dam.

The dam was modified by the Bureau of Reclamation in 1999 and 2000 to correct seepage, stability, and hydrologic deficiencies. The dam crest was approximately 20 below the overlook. There was no vehicular access to the dam prior to modification, and the only foot access was down a steep abutment via a pedestrian walkway with stairs which were a part of the trail head.

To provide access during construction, vehicular access for long-term maintenance of the dam, and easier visitor pedestrian access, an access road was constructed down the abutment to the dam crest. The access road begins at one end of the overlook and is to be used by NPS maintenance vehicles only.

To ensure that visitors on the heavily used Parkway would not fall down the access road and onto the dam crest in their vehicles, two bollards were placed at the start of the access road (see photos 1-3 and drawings 1 and 2).

Photo 1

The design objectives for the bollards were:

- Provide a barrier sturdy enough to withstand mechanized attempts to move it
- Provide resistance to casual unauthorized attempts at removal but be removable by NPS maintenance forces when necessary
- Be visually acceptable in the Parkway surroundings
- Not restrict pedestrian access on the hiking trail

The bollards satisfied the design objectives. They are rugged and should provide significant resistance to unauthorized vehicular access. The removable posts are heavy enough that a

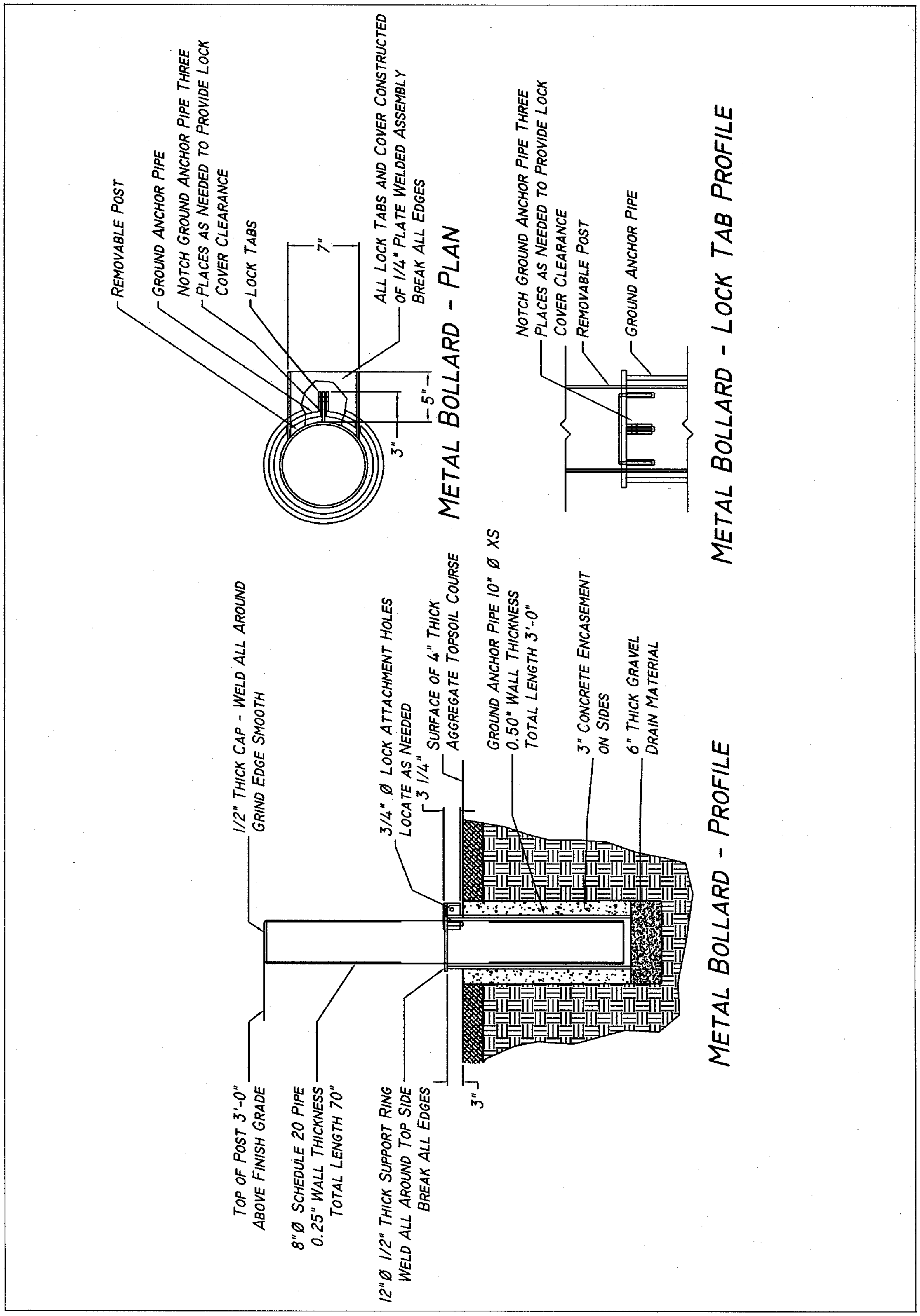
Photo 2

dedicated effort is required to remove the posts, even when not padlocked. NPS personnel selected the finish color for the bollards to match other Parkway facilities. Pedestrians pass unobstructed between the bollards on the hiking trail.

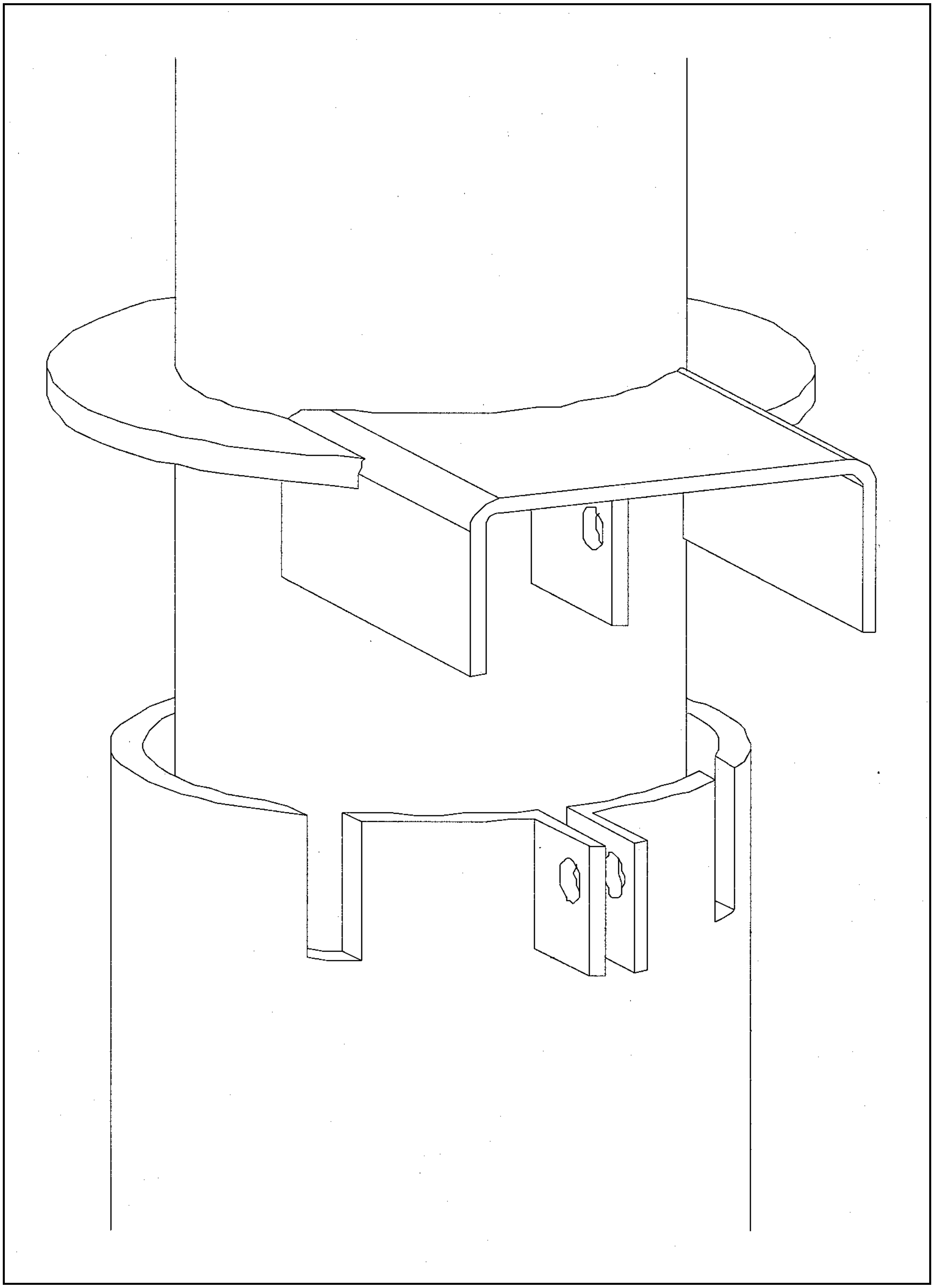
The bollards were installed under a lump sum pay item in the dam modification construction contract and cost $2,048 in place.

Were the bollards to be designed today, lifting handles would be added to the removable posts. The handles would be attached solidly enough for safe lifting but not be attached firmly enough to provide an attachment point for attempted unauthorized removal. Also, the lock would be raised slightly to provide easier authorized access to the padlock yet retain the lock protection and ease of access over the embedded anchor pipes.

Photo 3


REMOVABLE POST
GROUND ANCHOR PIPE
NOTCH GROUND ANCHOR PIPE THREE PLACES AS NEEDED TO PROVIDE LOCK COVER CLEARANCE
LOCK TABS
7"
ALL LOCK TABS AND COVER CONSTRUCTED OF 1/4" PLATE WELDED ASSEMBLY BREAK ALL EDGES
5"
3"
METAL BOLLARD - PLAN
NOTCH GROUND ANCHOR PIPE THREE PLACES AS NEEDED TO PROVIDE LOCK COVER CLEARANCE
REMOVABLE POST
GROUND ANCHOR PIPE
METAL BOLLARD - LOCK TAB PROFILE
1/2" THICK CAP - WELD ALL AROUND GRIND EDGE SMOOTH
3/4" Ø LOCK ATTACHMENT HOLES LOCATE AS NEEDED
3 1/4"
SURFACE OF 4" THICK AGGREGATE TOPSOIL COURSE
GROUND ANCHOR PIPE 10" Ø XS 0.50" WALL THICKNESS TOTAL LENGTH 3'-0"
3" CONCRETE ENCASEMENT ON SIDES
6" THICK GRAVEL DRAIN MATERIAL
TOP OF POST 3'-0" ABOVE FINISH GRADE
8"Ø SCHEDULE 20 PIPE 0.25" WALL THICKNESS TOTAL LENGTH 70"
12"Ø 1/2" THICK SUPPORT RING WELD ALL AROUND TOP SIDE BREAK ALL EDGES
3"
METAL BOLLARD - PROFILE

Drawing 1



Drawing 2

RADIAL GATE, HELD IN PLACE WITHOUT BOLTS FOR 14 YEARS, FINALLY FAILS

by Pete Hoffmann, Mechanical Engineer, Bureau of Reclamation

Introduction

On October 3, 2000, during a routine associated facility inspection at the Spanish Fork Diversion Dam, Utah (photo 1), the middle (gate No. 2) of the three radial gates on the diversion structure failed. The result of one subsequent inspection was shocking: the radial gate, which had no positive mechanical connection to its concrete corbel (for probably 14 years), fell off its support! Fortunately, nobody was hurt and little damage occurred to the radial gate itself. Because of stoplog slots and on-site stoplogs, the canal was back in service the following day, with no significant loss of water. Riverflow was relatively low because it was not irrigation season.

Photo 1.—Downstream view of diversion structure. A mobile crane removes the middle (failed) gate (No. 2).

The failure caused both arms of the radial gate to simply fall off the concrete corbel thrust block and into the gate bay (photo 2). The amazing part is that this gate had no positive mechanical connection holding it to its corbel, which in all probability and very interestingly has been for the last 14 years, ever since it was originally installed. It was not until last month, when the gate was routinely exercised from its fully open position to a closed position, that the arms came off the pedestal and fell into the gate bay.

Photo 2.—Middle (failed) gate (No. 2). Note that the arms have fallen off the concrete corbel support.

Radial Gate Description

Three consultant-designed radial gates of two different sizes were installed at the Spanish Fork Diversion Dam in 1986. The two larger gates (gate Nos. 1 and 2) are 20 feet wide by 16 feet high (photo 3), and the one smaller gate is 15 feet wide by 16 feet high. Except for their size, the three gates are similar and have similarly sized structural components. The arm assembly of each is fabricated from three wide-flange beams attached to three horizontal girders

Photo 3.—The larger 20-foot by 16-foot radial gate (No. 2) is removed from the structure.

supporting the stiffened faceplate. At the pin end of each of the three arms, two 1-inch-thick plates are welded to the flanges of the beams. The two plates support a 3-1/2-inch-diameter stainless steel trunnion pin (photo 4). Each trunnion pin is welded to the plates.

The commercial journal bearing housing supporting the pin is a split-bearing assembly, comprising a bushing, a housing, and mounting feet. The bushing is a self-lubricating bronze bushing with graphite-insert lubricants. The bearing housing is cast iron. The 4 feet of the journal bearing are bolted to a steel bearing plate which, in turn, is mounted using a double-nut system to four 3/4-inch-diameter anchor bolts embedded in the concrete corbel (photo 5). In the approximately 1-1/2-inch space between the bearing plate and the concrete corbel, grout provides the bearing surface for transferring the pin loads to the corbel and pier.

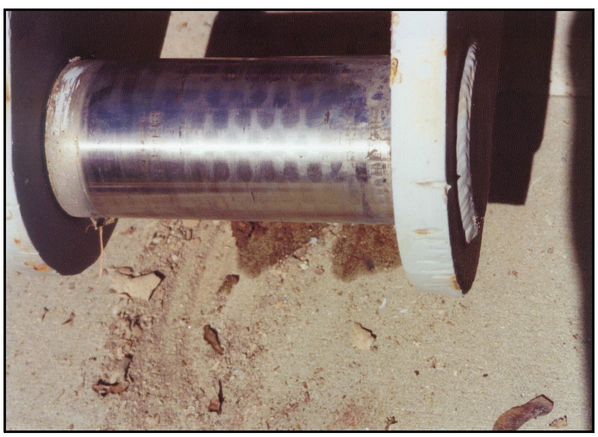


Photo 4.—Typical trunnion design. Stainless steel pin (3-1/2-inch diameter) welded on both ends to the 1-inch-thick plates.

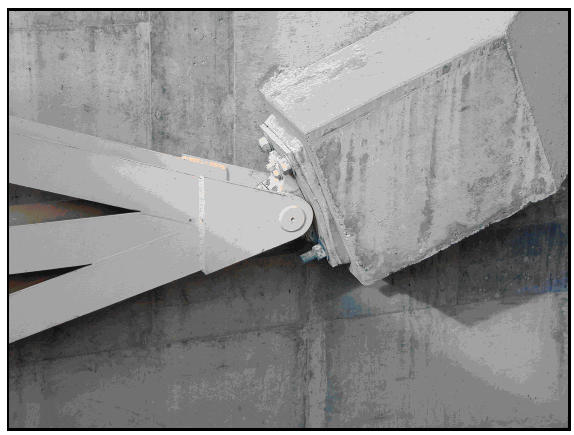


Photo 5.—Radial Gate No. 1, left arm assembly. Note the bent bearing plate, the bearing grout pad, and the concrete corbel support.

The journal bearing and housing is the assembly used to support the trunnion pin. This assembly transfers the hydrostatic load from the faceplates/arms into the concrete corbel.

Gate Operation at the Time of the Incident

At the start of the exercise, gate No. 2 was found in the open, or up, position. When the gate was lowered towards the closed position, one side of the faceplate settled unevenly on an approximately 2-foot-high gravel bar. Gravel or sediment in the river commonly settles unevenly to on one side or the other of the radial gate sill. When the gate was raised slightly to sluice the materials under the gate, the arms of the radial gate fell into the river, and the gate settled downstream slightly. The only attachment then holding the gates was the hoist cables.

The next day, the gate was removed from the gate bay and set alongside the structure for repairs. The journal bearing on the left side had a tight fit on the pin and could not be budged. Both cast iron bases on the journal bearings were cracked and broken free from their mounting feet, which were bolted to the bearing (photos 6 and 7). The surfaces of the cracked housing appeared very rusted, an indication that the crack had occurred a long time ago.

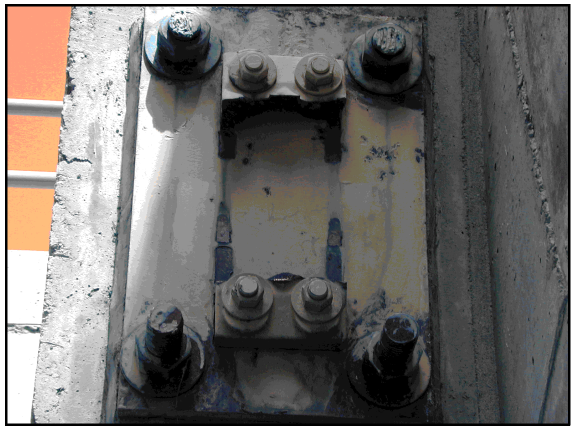


Photo 6.—Radial gate No. 2 (failed) showing the bearing plate attached to the embedded anchor bolts with the failed cast iron journal bearing housing cracked at the bolted connections.

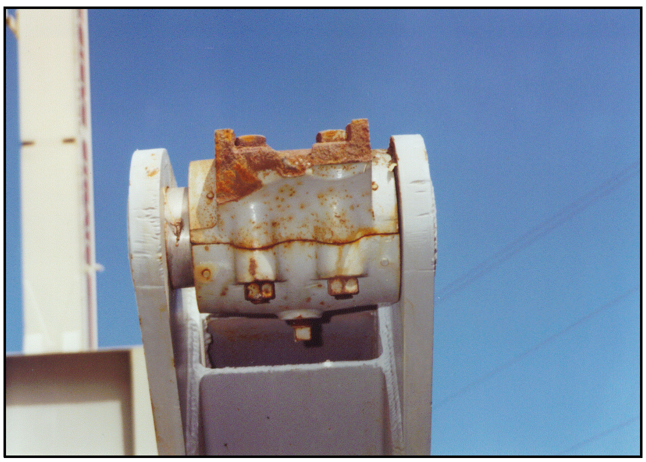


Photo 7.—End of the radial gate arm assembly showing broken journal bearing attached to stainless steel pin. Note that the cracked surfaces are very rusted and the bearing is completely shifted to the right end of the pin.

Why the Gate Fell – Factors Contributing to the Failure

Undersized Journal Bearings

The primary cause of the gate failure was the grossly undersized pin journal bearing supporting the trunnion pin. This bearing was a commercial product from an established bearing manufacturer. The published working load for the journal bearing used for the radial gate was 6,000 pounds of force. However, the actual force on the trunnion pin under full water head on the radial gate is 86,000 pounds. It was assumed that the first time water began loading the faceplate, the cast iron bearing housing cracked and failed immediately. Failure probably occurred when the water load exceeded the bearings' ratings times its factor of safety.

If a grossly undersized journal bearing caused the gate No. 2 failure, then shouldn't gate No. 1 have failed as well? That in fact was the case, as was noticed from a distant visual observation of the journal bearing for the other 20-foot by 16-foot radial gate (gate No. 1). Consequently, an operating restriction was immediately placed on gate No. 1. (Gate No. 3, the smaller radial gate on the left side of the structure, was visually examined, and no cracks in the journal bearing were found.)

Both bearing housings for the left and right radial gate arm assemblies for gate No. 1 had completely cracked at both the upper and lower locations where each attached to the bearing plate (photo 6). After the bearing housing had completely cracked, in effect, the radial gate was no longer connected to the concrete corbel!

So, what held the radial gate to the corbel all these years and allowed it to operate successfully for 14 years? Surprisingly, not much. Probably a combination of its wire ropes and the compression force of water held it against the corbel, along with any wedging and tight-pinching forces of the two pieces of the cracked housing. After the gate failure, gouge marks on the bearing plate were noticed (photo 6). These were probably due to the rocking motion of the feet on the bottom of the journal bearing housing as the gate was operated. The depth of the gouge marks is an indication of the long-term nature of the failure.

Undetected Failed Structural Component

That a radial gate could operate for 14 years with a broken journal bearing housing and without any positive mechanical (bolted) connection holding the gate in place is amazing. But, it is unfortunate that such a defect would go undetected for that long. It is understandable though. Because the trunnion assembly was inaccessible for close examination, and the angle of the corbel made viewing difficult, the hairline crack in the cast iron housing would have been hard to spot. The only other indication of a problem was the low clunking sound that could be heard whenever the gates were operated. However, the source of the sound was not recognizable.

The deformed bearing plates are certainly noticeable from the structure (see next section). Anytime a structural element appears deformed, a red flag should be raised and questions asked to explain the cause of overloading and deformation of the element. Again, the answer was known and appeared straightforward (see next section).

Untimely Gate Loading Before Placement of Grout Behind the Bearing Plate

Although not necessarily a primary cause of the journal bearing cracking and failure, the radial gates were loaded with water before any grout was placed behind the bearing plates.

Typically, during the construction and installation of radial gates, bearing plates are mounted on the embedded anchor bolts of the thrust blocks and positioned using a double-nut system. Usually, there is a 1-1/2- to 2-inch space behind a bearing plate where a grout bearing pad is placed. The grout is allowed to cure to full strength before the gates are loaded (photo 8). The load on the bearing plate is meant to be transferred into the grout pad.

However, at Spanish Fork Diversion Dam, the radial gates were loaded to an unknown height of water on the upstream side of the faceplate prior to grouting behind the plates. This was recalled during the site inspection. This caused the unsupported bearing plates to carry the load in bending and resulted in a deflected and deformed shape. Strangely, the effect for the gate that failed (No. 2) (photo 8) was not as pronounced as that for gate that did not fail (No. 1) (photo 5). After loading, grout was placed behind the deformed bearing plates. The journal bearing housing may have cracked at that time as well, depending on the level of loading of the gate.

Photo 8.—Radial gate No. 2 (failed) showing the bent bearing plate with the grout pad behind the bearing plate.

Gravel and Sediment Buildup on Sill Plates

The reason the arms of radial gate No. 2 happened to fall off the corbel during the inspection is somewhat clear. The diversion structure is located in a riverbed which is capable of transporting and depositing considerable amounts of gravel and sediment (photo 9). Gravel material 2 to 4 feet thick can settle out atop the sill plate. The accumulation of gravel on the sill is uneven. One side of the sill may have no gravel, while the other side has up to 4 feet! When the gate is lowered to rest on this uneven mound of gravel, then the gate faceplate begins to tip and rack, and the arms and pin bearing are subjected to a twisting force. This torque on the bearing journal apparently was enough to pop and free the one broken housing from its mating broken piece attached to the bearing plate. In such a situation, even with an adequately design trunnion pin bearing assembly, a normal bearing assembly is not designed to withstand this amount of torque.

Photo 9.—Upstream view of diversion structure with the failed middle gate removed and the stoplog installed in the slots.

Lessons Learned

For most radial gate installations within the Bureau of Reclamation (Reclamation), the unusual conditions that contributed to gate failure do not apply. Nevertheless, four general lessons can be learned from this failure.

- Keep in mind that there are limitations to any inspection. Normal inspections do not always uncover all deficiencies. Many components of mechanical equipment are hidden, housed, or generally inaccessible and unavailable during inspections. Unless a specific examination is performed, most radial gate trunnion bearing assemblies are inaccessible for close inspection. Whenever possible, and whenever inspection opportunities presents themselves, it would be beneficial to take the time to perform a closer exam of the structural and mechanical components.

- Identify radial gate installations where sediment or debris can routinely buildup on the sill plate. We must understand that when a radial gate is lowered on a gravel bar, the gate is likely to be racked and that a torque will be generated by the unsupported weight of the radial gates. This unsupported force will react with the pin bearing assembly—a force the assembly is not designed for. Often, rivers are extremely turbid, and the gravel buildup cannot be seen. In cases, where it is believed that gravel or debris may be building, but a visual confirmation cannot be made, an engineered solution should be investigated and implemented to ensure that the radial gates are not set down with their full weight on an uneven surface.

- Trust your intuition regarding the stability of gate components. Sometimes we can detect a poor design just by looking at it. Though observation may not determine unequivocally whether a component is properly designed or not, sometimes personal experiences and intuition are valuable. If, for instance, a structural component appears too small or flimsy, there is a good chance that it probably is. After the radial gate failure at Folsom Dam, people commented that the radial gate arms had appeared just too flimsy. Certainly, that was the case. So, when a structural component looks flimsier the more you look at it, trust your intuition and question whether or not there might be a problem.

- When possible, diversion structures should have stoplog slots upstream of radial gates, and stoplogs should be constructed and stored on site. Because the water users had stoplogs stored on site for immediate installation in the stoplog slots, the canal was back in service the following day, with no significant loss of water.

Additional Description – Spanish Fork Diversion Dam

The Spanish Fork Diversion Dam diverts Strawberry Reservoir releases into the Strawberry Power Canal, which supplies the Springville-Mapleton Lateral and the High Line Canal. The diversion dam was rebuilt in 1986. It was designed by Reclamation, with the exception of the radial gates, which were designed by an outside engineering firm.

Spanish Fork Diversion Dam has a structural height of 34 feet and a hydraulic height of 18 feet. The crest length is about 150 feet (photo 1). The discharge capacity of the three gates is 4,700 cubic feet per second. An overflow chute is located between the rivergate structure and the power canal headworks. The chute is 4 feet wide, with an apron elevation of 4854.0 mean sea level. The chute allows floating debris to bypass the diversion structure without opening a sluice gate. Each radial gate of the rivergate structure is provided with stoplog guides.

A Power Canal extends 3.3 miles from the diversion dam to the Spanish Fork Powerplants. It has a diversion capacity of 500 cubic feet per second. The Springville-Mapleton Lateral branches from the Power Canal 2 miles below the diversion dam. The lateral is 6.75 miles long and has a diversion capacity of 100 cubic feet per second. The High Line Canal begins above the Spanish Fork Powerplants where the Power Canal ends and extends 17.5 miles in a southwesterly direction. The diversion capacity is 300 cubic feet per second. Water from these canals is distributed through privately constructed laterals.

Mission

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

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