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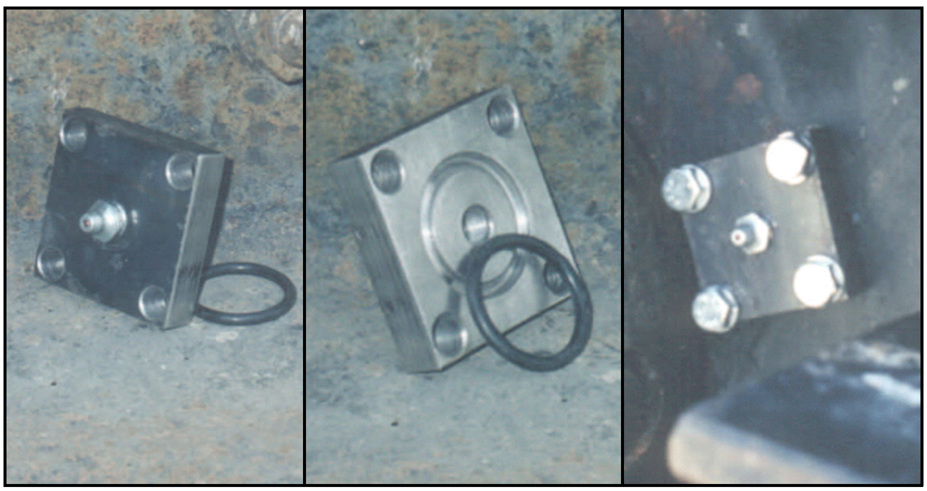

IN THIS ISSUE. . .

UNITED STATES DEPARTMENT OF THE INTERIOR **Bureau of Reclamation**

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***Cover photograph**: (a) Front side of a grease block fitting, (b) back side of a grease block fitting, and (c) a grease block fitting with "O" ring installed.*

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CONTENTS

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SPILLWAY GATE FAILURE OR MISOPERATION: REPRESENTATIVE CASE HISTORIES

by Wayne J. Graham, P.E., and Robert C. Hilldale[1]

Introduction

A spillway may be controlled or uncontrolled; a controlled spillway is provided with gates or other facilities so that the outflow rate can be adjusted. The most widely used type of gate for large installations is the radial (or tainter) gate. A gated spillway provides for greater flexibility in reservoir operation than a dam having an uncontrolled spillway.

The failure, misoperation, or use of spillway gates may cause downstream flooding that can range from minor to catastrophic. Downstream flooding is possible from any of the following:

R Spillway gates fail to open when directed. This could be caused by loss of electrical power; undersized motors; failure of automatic control systems; corrosion of wire ropes, rope connections, or bolted connections; failure of cart-mounted hoist equipment; displacement of concrete structural components; lack of maintenance; or other design or operational defects. If gates cannot be opened during a major inflow at a reservoir, dam overtopping and possible dam failure may result. If dam failure does not occur, the reduced outflow from the dam may have the benefit of reducing downstream flood damage.

R Spillway gates open accidentally through failure of automation equipment or some other unexpected occurrence.

R Spillway gates are opened intentionally during a major flood in accordance with a flood operating plan. This may cause major downstream flooding, but will reduce the chance of dam overtopping and possible failure. The flooding may impact many people, and those affected may question whether the spillways were operated correctly. (Such questions of reservoir and dam operation are always easier to answer with the benefit of hindsight.)

R Spillway gates fail structurally because of a deficiency in gate design or lack of maintenance, causing a sudden increase in discharge downstream from the dam.

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[1] Dam Safety Office Report No. DSO-01-01, Department of the Interior, Bureau of Reclamation, September 2001.

- R Debris blockage of spillway gates impedes outflow, possibly leading to damage to spillway gates and/or overtopping and dam failure.

- R Spillway gates are operated incorrectly. It is possible that some cases of misoperation go unreported. One case study of misoperation is contained in this document.

Representative Cases

1. Spillway Gates Failed to Open in Several Cases Reviewed

San Teresa Dam is located on the Tormes River in Spain. Construction of the 194-foot (59-meter) high earthfill dam was completed in 1960. In 1963, the malfunction of automatic controls of five 52.5-foot (16-meter) long tainter gates led to overtopping and foundation erosion (Laa et al., 1979).

Picote Dam is located on the international reach of the Douro River in Portugal. On February 16, 1966, during a flood, the hoist chains failed when the gates were being opened by remote control. The cause of the accident was later determined to have been a lack of articulation in the chain links on the left side of the gate (caused by the accumulation of debris). The lack of articulation of the chain led to failure of the motor on the left side. The motor on the right side of the gate continued to operate, causing the gate to warp. The friction resulting from warping of the gate led to the failure of the right motor. The gate descended from its own weight, causing the gate to land forcibly on the sill. This resulted in the trunnion girders being torn from the fan, causing the gate to wash downstream. The accident put the two adjoining gates out of use and in the up (open) position because of lack of support of one end frame. Dam failure did not occur, and downstream damage was not reported (Lemos et al., 1973).

Tous Dam was located on the Jucar River in Spain. On October 20, 1982, a flood of exceptional magnitude (500-year return period) began to overtop the crest of the earth and rockfill dam. The spillway was composed of three steel gates, each 52.5 feet (16 meters) high and 34.5 feet (10.5 meters) wide. The electricity supplied to the spillway gates had failed as a result of the storm, and all efforts to open the gates were unsuccessful. This caused the dam to overtop, which eroded the central body of the dam, leading to failure. A flood volume of approximately 502,000 acre-feet (620,000,000 cubic meters) entered Tous Reservoir. A volume of water of about 49,000 acre-feet (60,000,000 cubic meters), stored in the reservoir, was added to the flood. It is apparent that the amount of water contained in the reservoir was a small fraction of the total amount of water entering the reservoir. The peak outflow from the failure reached about 565,000 cubic feet per second (ft^3/s) (16,000 cubic meters per second [m^3/s]), and just downstream of the dam, flood depths were 82 feet (25 meters) above the ground level. The damage caused by the flood, increased somewhat by the failure of the dam, destroyed 240 houses and damaged 14,000 others. Railways, highways, and irrigation systems were also damaged. Severe flooding and damage would have occurred in downstream areas even if the dam had not failed (Utrillas et al., 1992).

In May 1986, lightning struck the interconnection tie line to the Upriver Dam Hydroelectric Project in Spokane, Washington. The lightning strike caused a fault in the generators, forcing the turbines to reject a surge of water. Both remote and manual attempts failed to open the radial gates in an effort to pass the riverflow. This caused the Spokane River to breach the closure embankments and the dam abutments of Powerhouse #1. Normal service was restored to Powerhouse #2, but it was 6-1/2 hours before a generator could be connected to the spillway gates to lower the level of the river. Powerhouse #1 was completely surrounded by water, and material was eroded from the foundation. The powerhouse was left tilting 1-1/2 degrees upstream. Damage from this incident totaled $11 million; however, it was limited to the structures of the project and the immediate area (Hokenson, 1988).

Belci Dam, a clay core earthfill structure, was located on the Tazldu River in northeast Romania. During the night of July 28-29, 1991, torrential rainfall of an exceptional magnitude occurred. The spillway at the dam was composed of radial and flap gates. The supply of electricity to the dam failed, preventing the full opening of the gates. One radial gate had been lifted by only 1.3 feet (40 centimeters) at the time of the power outage, and the other radial gate never opened. Dam operating personnel tried to unblock and lower the flaps manually. After the dam failure, it was found that three of the four flap gates remained blocked. The peak inflow to the reservoir was about 77,700 ft^3/s (2,200 m^3/s), and the peak outflow from dam failure was about 106,000 ft^3/s (3,000 m^3/s). The flood and the resulting dam failure had disastrous consequences. Slobozia, a village 1.2 miles (2 kilometers) downstream from the dam, was largely destroyed; 17 lives were lost, 119 houses were completely destroyed, and 24 houses were damaged. The main flooding of Slobozia occurred at 06:30 hours. Warning was initiated at 02:15 hours, approximately 4 hours before the main flood hit Slobozia. However, "the warning of the population downstream on the night of the accident was not sufficiently vigorous or efficient." The peak reservoir inflow was nearly 75 percent of the dam failure outflow, so even in the absence of dam failure, major downstream losses probably would have occurred. The exceptional torrential rainfall caused widespread damage to the whole of Bacau County. A total of 78 people were killed, and 19 were reported missing (Diacon et al., 1992).

Tarbela Dam is located on the Indus River in Pakistan. On June 23, 1992, after 17 years of normal operation, hoist ropes failed after a radial gate jammed during a lowering operation. Before the failure, all the spillway gates were in the open position and passing a total discharge of 87,392 ft^3/s (2,475 m^3/s). During the closing operation, the far right gate became stuck in the open position, approximately 4.4 inches (11.2 centimeters) above the sill. This caused a high velocity discharge from the small opening, which could potentially cause damage to the sill plate and concrete surface. The malfunction was caused by a decrease in clearance between the seal clamping bar and side seal plate. Bolts fixing the clamping bar to the skin plate had backed out, decreasing clearance to less than what is required for thermal expansion. The dam did not fail and no downstream damage was reported (Khan and Siddiqui, 1994).

An article by Watson (1997) summarizes other cases in which the inability to operate gates led to dam failure. A power failure leading to gate malfunction resulted in the overtopping and failure of the Chikkahole Dam in India. The malfunction of radial gates during a flood resulted in overtopping and failure of the Russian Tirlyan Dam and more than 20 fatalities. Gates that fail to open when needed are a preventable cause of dam failure.

2. Spillway Gates Open Accidentally or by Automation Error

Mav...i...e Dam is located on the Sava River in the central part of Slovenia. On March 7, 1993, at 11:30 hours, the radial gate on the second spillway began to rise automatically. The cause of the opening was an uncontrolled automatic start of the oil pump, which opened the hydraulic valve for raising the radial gate on the automatic gate system. At the time of full spillway opening, the discharge was 42,100 ft^3/s (1, 192 m^3/s), approximately equal to the flood discharge with a 50-year return period. In the area downstream from the dam, the flood wave caused some erosion of the embankment. Downstream from Mav...i...e Dam, the riverbed runs in an uninhabited canyon. Farther downstream, there was some minor damage done to two regulation buildings located in the river channel below a second dam (Rajar and Kryzanowski, 1994).

In 1989, the forebay radial gate on the Seton Dam in British Columbia opened automatically when the hoist motor energized itself without warning. Water in an electrical conduit had frozen around the 460-volt, three-phase power supply leads. The expanding ice in the conduit pushed the leads upward, forcing the contacts closed, thus energizing the motor. The hoist raised the gate past the fully open position, causing the gate to hit the upper stop-beam. This caused the fuses in the circuit to blow, but not before structural damage had occurred to the gate arms and skin plate. The extent of downstream damage, if any, was not reported (M. Watson, 1997).

3. Spillway Gates Opened Intentionally During a Major Flood

In September 1998, government officials in the Dominican Republic ordered the flood gates to be opened at Sabaneta Dam, which was about to burst as a result of Hurricane Georges striking the island. It has been reported that the water was released without evacuating or even notifying the villagers down river in the town of Mesopotamia. Opening of the gates at Sabaneta Dam contributed to the deaths of numerous individuals in the city of Mesopotamia. The Dominican Government chose to ignore warnings from the U.S. that predicted the path of Hurricane Georges (Fineman, 1998). A response report by McEntire (1999) states that the Dominican Government did not want to alarm the population or have to open an excessive amount of shelters. While the storm was tearing through the island, the government radio station was playing music and discussing recipes rather than providing details about the storm. Had warnings from the U.S. been heeded, the gates at Sabaneta could have been opened before and during the storm to pass the flood waters, preventing a near failure condition at the dam and allowing time for proper warning of downstream inhabitants.

During heavy seasonal rains that fell in early October 1999, Nigeria's National Electric Power Authority released water (opened the floodgates) at Jebba and Shiriro Dams on the Niger River to prevent the dams from overtopping. The resultant flooding submerged 400 villages, killing hundreds and leaving 300,000 homeless. The amount of water released from the dams was not reported (Associated Press, October 1999).

A similar case involving the release of water from the Penitas Dam in the State of Chiapas, Mexico, occurred in October 1999. Heavy damage resulted. Following accusations of misoperation, the Regional Director of the National Water Commission stated that, “We are not responsible.” Government officials said that the flood gates had to be opened to prevent the dam from breaking and causing an even greater disaster (Associated Press, December 1999). Authorities stated that the release would be gradual, causing no further damages, despite an expected downstream water level increase of as much as 20 inches (50.8 centimeters). More than 400 deaths were blamed on the flood (J. Watson, 1999).

4. Spillway Gates Fail, Causing a Sudden Increase in Outflow from the Dam

In 1986, one of two drum gates inadvertently opened at the southern spillway of Guernsey Dam in Wyoming. Debris left inside the gate by a painting contractor resulted in plugged drain lines. The interior of the gate filled with water, resulting in a loss of buoyancy. The gate reportedly opened approximately half way in 7 hours before the debris was cleared from the drain (Read, 2000). Peak discharge values are unavailable; however, the downstream capacity was never exceeded during the incident (Lux, personal communication, 2001).

In October 1990, 1 of 17 radial spillway gates failed on the Singur Dam in Andhra Pradesh, India. This failure occurred during initial filling of the reservoir when the water level was 9.8 feet (3 meters) below design level. The gate became dislodged due to a detachment of the left side trunnion girder. The right side arm supported the gate for 22 hours before becoming completely dislodged and washing away. The Andhra Pradesh State authorities attributed the failure of the gate to inadequate welding between the trunnion girder and the tie flats (Mande et al., 2000). There is no mention of downstream damage resulting from this failure.

On July 17, 1995, at about 08:00 hours, a radial gate at Folsom Dam buckled and collapsed. The failure increased flows into the lower American River by 40,000 ft^3/s (1,133 m^3/s), which was flowing at 6,500 ft^3/s (184 m^3/s) at the time of the failure. The peak outflow resulting from the buckled gate was less than releases made from the dam in March of the same year (51,300 ft^3/s or 1,450 m^3/s) recorded at the American River at Fair Oaks gauge. In addition, the outflow of 46,500 ft^3/s (1, 133 m^3/s) from spillway failure was well within the capacity of the levees that line the American River through Sacramento. No deaths or major damage was recorded downstream from Folsom Dam as a result of the spillway gate failure (Hindley, 1996). Two lifeguards in a state patrol boat had a close call with death 3 days after the gate failed. The pair was patrolling the waters near Folsom Dam to keep others away from the broken spillway gate. The inboard engine on the 17-foot aluminum jet boat they were in failed to start after it had been turned off to save fuel. The boat started drifting toward the water rushing over the failed spillway gate, and both jumped out (wearing personal floatation devices) and successfully swam 200 yards (183 meters) to shore. The mangled remains of the boat were recovered downstream from the dam.

A drum gate, 124 feet (37.8 meters) long and 28 feet (8.5 meters) high, failed at Cresta Dam, which is located on the North Fork of the Feather River, approximately 30 miles (48.2 kilometers) east of Oroville, California. The failure occurred at 12:30 hours on Saturday, July 5, 1997, during the busy July 4th weekend. The mean daily flows in the days prior to the failure were approximately 70 ft^3/s (2 m^3/s). The maximum discharge during the gate failure was about 15,000 ft^3/s (425 m^3/s). Pacific Gas and Electric, the owner of the dam, estimated that over a 40-minute period, the river stage increased 13.5 feet (4.1 meters) at a location approximately 1 mile (1.6 kilometers) downstream from Cresta Dam. The peak discharge released from the dam, although greater than the reservoir inflow at the time, was far less than the highest flows that have occurred on this river. On January 1, 1997, a record discharge of 115,000 ft^3/s (3,257 m^3/s) was recorded at a gauge located 2.1 miles (3.4 kilometers) downstream from Cresta Dam. Flows greater than 15,000 ft^3/s (425 m^3/s) occurred in 7 of the 13 years between 1986 and 1998.

The gate failure did not impact any structures or highways (Water Commission Report, 1997). The flooding did impact recreationists downstream from the dam. Rafters were capsized, and fishermen, campers, and picnickers were scattered by the surge. In two cases, people left stranded had to be rescued by helicopter. A local newspaper reported, "Many anglers and swimmers were alerted to the danger by a woman who drove down the canyon honking her horn and yelling, 'Get out! Get out!. . .'" at everyone she saw (Wiley and Little, 1997).

The chain of events that lead to the failure of the drum gate follows (taken from an update to the Water Commission Report, August 1997):

- Siltation in the reservoir blocked the 54-inch (137.3-centimeter) diameter water supply pipe to the floatation chamber.
- Limited flow capacity of the 24-inch (61.0-centimeter) backup supply pipe restricted flow into the floatation chamber.
- A severed atmospheric drain hose fitting from the drum gate permitted the drum gate to partially fill with water.

- A steel plate placed over the downstream end of the atmospheric drain prevented drainage from the drum.
- A failed check valve permitted water to flow into the drum gate through the severed hose fitting.
- Severely worn gate seals permitted excess leakage from the floatation chamber.
- The weight of the partially flooded drum gate overcame the buoyant lift supplied by the floatation chamber.
- Gate seal leakage exceeded the water supply from the 24-inch (61.0-centimeter) diameter backup pipe.

5. Debris Blockage Causing Reduced Spillway Capacity

In July 1996, a major storm hit the Saguenay region of Quebec, Canada, resulting in 11 inches (280 millimeters) of rain falling over a 72-hour period. High riverflows overtopped several dams in the region for a period of over 24 hours. The spillway gates on the Chute Garneau Dam were opened during the event in an attempt to pass the floodflow and prevent overtopping. During the high flow, the spillway gates were partially blocked with floating debris and sunken debris brought to the surface by high flows near the river bottom. The blockage reduced the capacity of the spillway gates, which contributed to the overtopping. As a result of overtopping, the river carved a new channel around the dam, eroding almost 200,000 cubic yards (150,000 cubic meters) of silt and clay, rendering the dam useless (Leger et al., 1998). It should be noted that debris blockage of the spillway gates was not the only cause of the incident. The gates had a capacity of 19,000 ft^3/s (540 m^3/s), but the maximum flow rate into the reservoir was 39,000 ft^3/s (1, 100 m^3/s).

Although debris blockage is not considered a failure or a misoperation of the spillway, it needs to be considered in an evaluation of spillway/dam failure when upstream debris flow is anticipated during a flood. It is important to note that ice can also create a blockage at spillway gates.

6. Spillway Misoperation Causes a Sudden Increase in Downstream Flow

On July 15, 1976, the lack of coordination between operations at two dams led to the accidental drowning deaths of two girls, ages 9 and 10, who were playing in a river. Mud Mountain Dam, operated by the U.S. Army Corps of Engineers, is located on the White River in western Washington. In the lower reaches, the White River is also known as the Stuck River. About 5.4 miles downstream from Mud Mountain Dam, there is a diversion dam operated by Puget Sound Power and Light. Pacific town park, where the girls drowned, was about 19 miles downstream from the diversion dam (or 24.4 miles downstream from Mud Mountain Dam).

The misoperation occurred when the operators at Mud Mountain Dam were attempting to coordinate their releases with the diversion dam to accommodate cleaning of trash racks in the intakes at Mud Mountain Dam. At nearly the same time that the outflow from Mud Mountain Dam was increased by 750 ft^3/s (21 m^3/s), operators at the diversion dam, because of high turbidity levels, removed flashboards from the diversion dam and ceased diverting 1,750 ft^3/s (50 m^3/s). These two changes occurred less than ½ hour apart, with the two waves arriving at the accident site at approximately the same time. The 1,750 ft^3/s (50 m^3/s) wave that was caused by the reduction in water being diverted out of the White River traveled faster and caught up to the first wave (the water released from Mud Mountain Dam) before arriving at the Pacific town park (site of the drownings) (Biggs, 1976). The changes in riverflow caused by the actions taken at the two dams caused the flow to increase from 100 ft^3/s (2.8 m^3/s) to over 2,000 ft^3/s (57 m^3/s) in just a few minutes at the Pacific town park. The increase in flow at this location caused the river level to rise by 3.0 to 3.5 feet (0.9 to 1.1 meters) (Biggs, 1976). The Seattle Times reported on July 16 that many people (including children) were cooling off in the White River the day of the accident, the hottest day of the year. The two girls who drowned had been playing on a sand bar in the river. Several other people who had been on the sand bar reached high ground with the help of a human chain formed by park visitors.

Sudden Release of Water From Spillway Gates

The sudden release of water from the opening of a spillway gate or gates can result in adverse downstream consequences. The sudden opening could result from a structural failure, which causes the gate to wash downstream, an automation error, or the intentional or unintentional act of a dam operator.

The release of water from a gate failure or gate opening may or may not endanger downstream life and property. The consequences resulting from the release might include injuries or deaths, property damage, environmental damage, damage to the facility itself, and/or the loss of project benefits.

Determining the incremental consequences caused by sudden releases can be challenging. The general rule in the United States is that the operator of a dam may permit floodwaters to pass over or through a dam in an amount equal to the inflow, but will be liable if any excess amount is discharged (NRC, 1985). Using this logic, the incremental consequences of a sudden release from opening a spillway gate would be the additional losses caused by the sudden release compared to the losses that would have occurred with the dam discharging flows equal to the reservoir inflow.

Another way of evaluating incremental damage would be to recognize that the dam, especially a flood control dam, has probably forever changed the flood characteristics of the area downstream from the dam. Because of the expectation of protection provided by the dam, land use in the downstream area has changed significantly compared to how the land would have been used if the dam had never been built. Therefore, incremental consequences of a sudden release from opening a spillway gate would be the additional losses caused by the sudden release compared to the losses that would have occurred if the sudden release had not been made. It may not be appropriate to use this second method for computing incremental consequences for major flood events. The sudden release of water from a dam, while causing downstream losses, prevents a possibly greater loss that might have occurred if the gates had not been opened and the dam had failed.

Estimating Losses Caused by the Sudden Release of Water from Spillway Gates

The unplanned opening of one or more spillway gates will cause the release of water stored in the reservoir. The time versus discharge characteristics of the release will depend on the reservoir level at the time of the opening as well as the rate at which the opening occurs. Damage from such an opening will attenuate with downstream distance. The rapid removal of a gate could result in more critical flooding than a gradual gate opening.

Reservoir contents released during a gate opening may exceed the channel capacity of the watercourse downstream from the dam. This is especially true if, during a high reservoir level, a large gate falls and water flows into a small river downstream from the dam.

The loss of life resulting from a sudden gate opening can be estimated using "A Procedure for Estimating Loss of Life Caused by Dam Failure," (DSO-99-06, Graham, 1999). Although the title of this reference document includes the words "dam failure," it focuses on flood events that occur suddenly and result in a very rapid increase in downstream flooding. Sudden releases from spillway gates may cause such a condition.

The procedure for estimating loss of life is composed of the following steps:

(1) Determine the gate failure scenarios to evaluate (e.g., how many gates fail or are opened?)

(2) Determine time categories (these impact warning and people at risk [PAR])

(3) Determine when warnings would be initiated

(4) Determine the area flooded for each scenario defined in (1)

(5) Estimate the number of PAR for each failure scenario and time category

(6) Select the appropriate fatality rate and estimate the loss of life

(7) Evaluate uncertainty

Details of each step are provided in DSO-99-06 (Graham, 1999). Steps 3, 4, and 5 deserve additional attention and are discussed below.

Step 3: It is not likely that warnings will be issued before an unplanned gate opening. A warning would likely begin after the gate is opened.

Step 4: This step requires determining the discharge released from the gate opening/failure as well as the area that would be flooded. The peak gate-failure discharge should be compared to the safe channel capacity (flood carrying capacity) of the watercourse downstream from the dam. The gate-failure discharge might be small or large when compared to commonly occurring discharges on the watercourse. Little or no damage to permanent structures would be anticipated if the gate-failure discharge frequently occurs in the watercourse. In the examples given earlier in this report (Folsom and Cresta Dam), the gate-failure discharges were less than commonly occurring annual peak discharges on their respective watercourse. When gate-failure discharges are small, recreationists such as boaters, anglers, picnickers, campers, and others may still be at risk.

There will be cases where gate-failure discharges are large in relation to common flows (e.g., when gate-failure discharges would be a record discharge or would exceed the 100-year flood discharge.) In these cases, damage to permanent structures is much more likely, and recreationists would again be at risk.

Step 5: Estimating the number of people at risk is especially difficult when evaluating the impacts of gate failure. For many dams, the failure of one spillway gate would place only recreationists and other temporary users of the floodplain at risk (e.g., Folsom gate failure). U.S. Census Bureau information showing the number of permanent residents is of no use in these situations. The number of people at risk at different times of the day and year will need to be determined by field trips or by talking to recreation specialists or others who are familiar with the area.

Preventive Measures

The losses incurred from the sudden opening of a spillway gate can most often be prevented. Following are some measures that can be taken to prevent the specific types of sudden gate openings or failures discussed in this report.

1. Spillway Gates Failed to Open

In the cases reviewed, spillway gates have failed to open because of either a mechanical failure or a power failure, both of which are preventable. Mechanical failures can often be prevented by a system of inspections and proper maintenance. Inspections can locate potential hazards such as corrosion, cracked welds, or other structural defects in gates or hoist chains/cables (Edwards and Plank, 1999). Proper maintenance of trunnion pins and other gate mechanisms prevents corrosion and additional (often unaccounted for) forces on gate members (Hindley, 1996). Electrical power to spillway gates is often lost during severe storms, when gate operation is most critical. Alternative opening mechanisms or a back-up power supply can be implemented for those gates that require electricity to operate.

2. Spillway Gates Opening by Automation Error

These types of failures are harder to prevent because of their unexpected nature of occurrence. Evaluating these types of failures before designing automated operating systems is the best method of preventing such failures.

3. Spillway Gates Were Opened Intentionally During a Major Flood

During major flood events, spillway gates need to be opened despite the downstream flooding that may occur. There is a potential for misoperation of spillway gates because of pressure from downstream interests to keep the gates closed and from inadequate detailed procedures describing gate operation during major flood events. Engineers are responsible for providing clear, written instructions to dam operators for every possible event (Hinks, 2001). Table-top exercises are one way to increase readiness for a dam emergency such as large floods or a gate failure. During these exercises, all key personnel are familiarized with procedures and the types of decisions that need to be made during an emergency.

4. Spillway Gates Failed, Resulting in the Release of Water

Failures of the type mentioned in this category often result from a combination of events. For example, the gate failure at Folsom Dam was more than corrosion, more than a lack of maintenance, and more than a lack of lubrication. It is probable that the gates were in an overstressed condition when reservoir levels were high because the connections and members were under-designed. Flow-induced vibrations and corrosion of the trunnion pins may also have contributed to the failure (Hindley, 1996).

The drum gate at Cresta Dam had a history of operational difficulties before the July 5 failure. In this case, a combination of plumbing failures led to flooding of the floatation chamber and subsequent failure of this gate. Inspections and routine maintenance of both spillways may have prevented both of these failures.

5. Debris Blockage Causing Reduced Spillway Capacity

Debris blockage of spillways (including ice) can lead to overtopping and, in some cases, dam failure. The Canadian Dam Safety Association states that a safe spillway should have "the capability to pass floating debris during the inflow design flood (IDF), or provision of an effective debris barrier designed for IDF loading" (Canadian Dam Safety Association, 1995). The Norwegian State Electricity Board has published a methodology (Norwegian Water Resources and Energy Administration, 1992) to assess spillway obstruction caused by floating debris (Leger et al., 1998).

Design Option for Existing Dams

Installing non-automated "tip-bucket" type gates at dams currently controlled by gated spillways has the potential to increase the safety of a dam. This type of gate allows for wide flexibility of operation and can be used as a backup to conventional gates during major floods. These gates are essentially a bucket that spills normal reservoir flow by overtopping until a designed reservoir elevation is reached, above which the bucket tips and falls away into the downstream flow. The gap left in the spillway allows reservoir contents to pass downstream at a greater flow than when the bucket was intact. This action is designed to occur in such a way that there is no significant sudden increase in reservoir outflow when these buckets tip and fall away (controlled by the dimensions of the bucket).

A major advantage of this type of gate is that no mechanical or electrical power is required at the time of operation during major floods. The triggering mechanism is water filling a chamber below the bucket, which increases its buoyancy enough to cause it to overturn in the downstream direction. Under certain conditions, "'tip-bucket" type gates may be an improvement over gates requiring mechanical or electrical power and personnel to operate them during a major flood.

INSTALLATION OF GREASE FITTING BLOCKS FOR AGENCY VALLEY DAM RADIAL GATES

by Curtis D. Carney,[1] Karl Ames,[2] Ernie Bachman,[3] and Daniel Meredith[4]

There are concerns about the lubrication of radial gate trunnion pins that have been documented in numerous reports and accented by the Folsom Dam radial gate failure. The Snake River Area Office technical personnel have developed a technique for installing grease fitting blocks on the side of the radial gate arms which allow grease to be pumped directly into the bearing surface of the trunnion pin and radial gate arm.

The spillway at Agency Valley Dam is located on the right abutment and consists of a gated structure, a step chute, and a stilling basin. Three 18-foot-wide by 17-foot-high spillway radial gates are installed on the crest of the spillway (refer to photograph Nos. 1 and 2). The spillway radial gates are numbered left to right looking downstream.

The spillway radial gates consist of a curved leaf, which are a true sector of a circle and two arms connected to pivots at the center of curvature (refer to photograph No. 3). The radial gate arms on these gates are somewhat unusual. They are built up of three parallel steel plate members—two being 1 inch thick and the other being ½ inch thick. The spillway radial gates are constructed of structural steel and are raised by means of double drum hoists located on the operating deck of the spillway structure.

The spillway radial gates are equipped with rubber side seals, which seat against embedded wall plates in the spillway radial gate structure. Seals along the bottom of the spillway radial gates are of timber.

There are no flashboards installed on top of the spillway radial gates. The top of the gates is at elevation 3340.0, which is the top of normal pool level.

The spillway gate arms have been modified for lubrication of the trunnion pins. This report describes the procedure used to install the lubrication grease fitting blocks for the trunnion pins.

The spillway gates were not watered-up at the time of this procedure because of a low water year.

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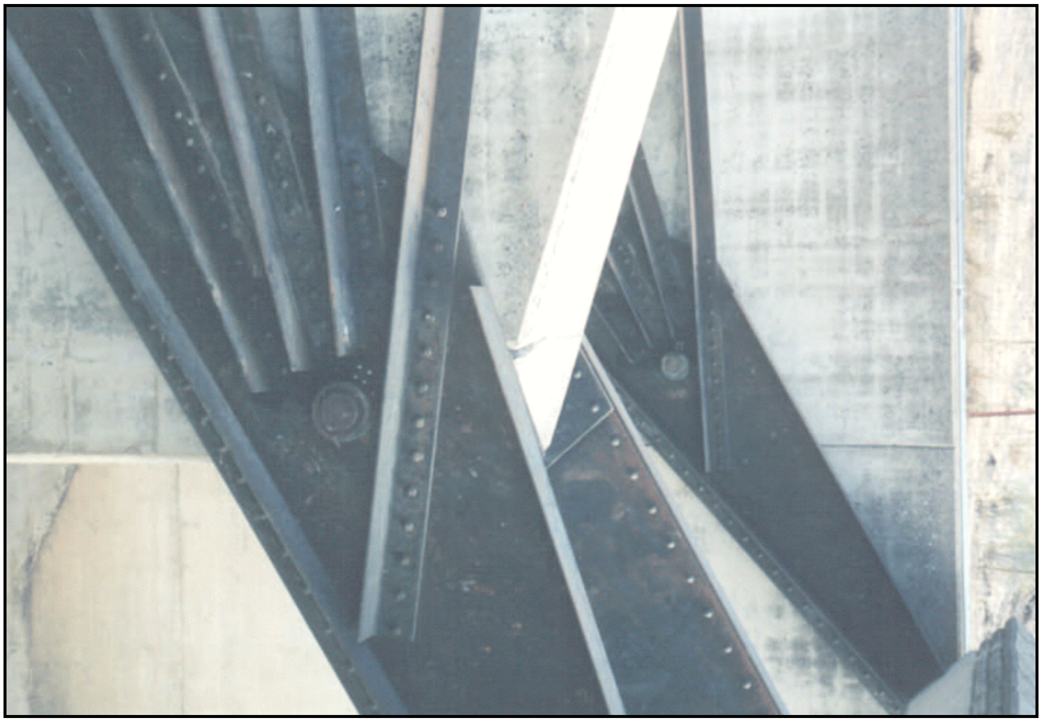
[2] Civil Engineer, Snake River Area Office.
[3] Mechanical Engineer, Snake River Area Office.
[4] Mechanical Engineer, PN Regional Office.

Photograph No. 1.—Radial gates as installed on the right embankment.

Photograph No. 2.—Back side of radial gates and gate arms.



Photograph No. 3.—Spillway radial gate arms and pivot points.

A. Description of Trunnion Pin Grease Block Fittings and Equipment/Supplies for Installation

(1) Six grease blocks were built by a local machine shop. They were constructed from mild steel, and 5/16-inch mounting holes were drilled, the block was drilled and tapped for 1/4-inch x 18 NPT, and then the block was grooved for 1/8-inch x 1-inch "0" ring (see sketch No. 1 and photograph Nos. 4, 5, and 6).

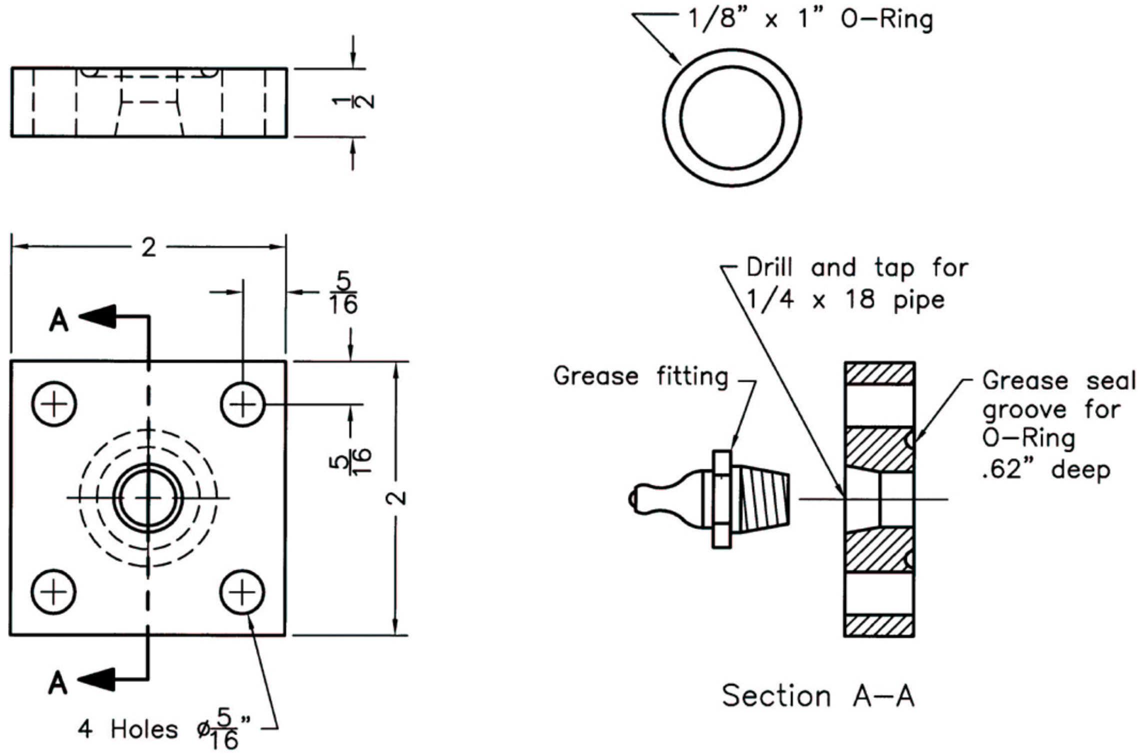
(2) Drills and taps needed are the following: 3/8-inch standard high-speed drill bits, 3/16-inch extra length drill bits, Letter F drill bits, and 5/16-inch x 18 UNC taps.

(3) 5/16 x 1-inch UNC bolts, 5/16-inch lock washers, cutting fluid, and tapping fluid.

(4) The 1/8-inch x 1-inch "0" ring grease seal should be made of neoprene or some other grease-resistant material.

(5) Before installing the grease fitting block, it should be cleaned, primed, and coated with a good quality exterior coating.

(6) Prior to installing the grease block onto the surface of the radial gate arm, the surface of the radial gate arm should be cleaned of all rust and corrosion and re-coated if necessary.



GREASE FITTING BLOCK

Sketch No. 1

Photograph No. 4.—Back side of a grease block fitting.

Photograph No. 5.—Front side of a grease block fitting.

Photograph No. 6.—Grease block fitting with "O" ring installed.

(7) An air compressor could be used to clean out drilled holes, but an oil can with a small spout could also be used.

(8) Appropriate safety equipment and equipment as needed to reach and work on gate arms.

B. Procedure Used to Install the Grease Fitting Blocks on Radial Gate Arms

(1) A Job Hazard Analysis (JHA) was developed, approved, and reviewed by the Vale Oregon Irrigation District staff and the Snake River Area Office staff.

(2) Three stages of scaffolding was setup to accommodate at stable work place for drilling and tapping sequences.

(3) Grease blocks were set at a desired location on the radial gate arm (the grease block at Agency Valley is located on the upstream side of the trunnion pin), bolt and grease fitting hole locations were transferred to the radial gate arm surface, and then the grease block was removed (see sketch No. 1). Ensure that the grease-fitting block is located in such a position so the 3/16-inch extra length drill bit drill can reach the trunnion pin.

(4) While using the 3/8-inch standard high-speed drill bit, drill a hole about 1/4-inch deep at the center punch mark for the grease fitting position (refer to photograph No. 7. (Use safety glasses when drilling.) This is done to give the 3/16-inch extra length drill bit a surface to start drilling at an angle toward the trunnion pin.

(5) Measure the distance the 3/16-inch extra length drill bit will have to penetrate into the radial gate arm to reach the trunnion pin and mark the 3/16-inch extra length drill bit.

CAUTION: The following procedure must be completed with care for limitations of equipment and supplies. Forcing the drill bit could result in breaking the drill bit, scaring the trunnion, or drilling into the trunnion pin.

(6) Position the 3/16-inch extra length drill bit in the 3/8-inch hole at an angle to reach the trunnion at its mid point and drill the 3/16-inch hole for the grease channel to the trunnion pin (refer to photograph No. 8). Use a high grade cutting oil to lubricate and cool the drill bit. It will be necessary to move the drill bit in and out of the hole often to break the chip out of the hole because the drill bit flutes may be buried in the hole before the trunnion pin is reached with the end of the drill bit (refer to photograph No. 8).

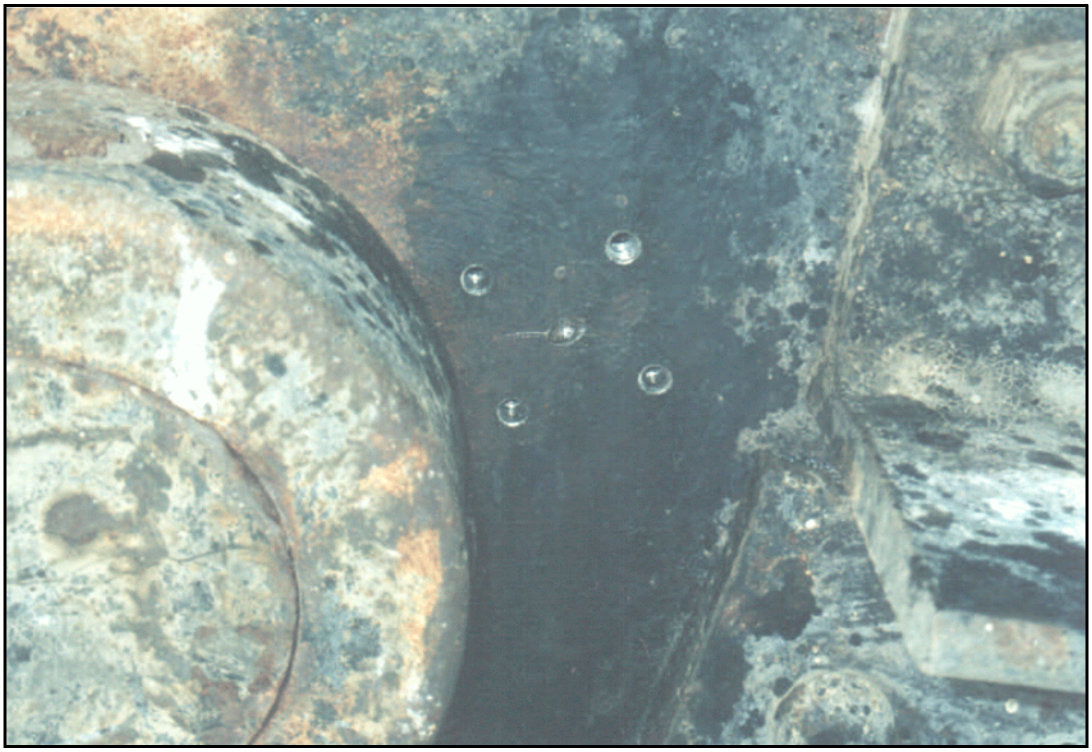
(7) Once the trunnion pin is touched by the 3/16-inch extra length drill bit (a different feel will occur while drilling when the trunnion pin is touched), cleanout the hole by blowing air into it with an air compressor or flushing it with a long-spouted oil can (use safety glasses and goggles when using compressed air).

(8) Drill and tap the other four grease block mounting bolt holes. Use Letter F tap drill (0.2570) for the 5/16-inch x 1-inch mounting bolts. Clean all holes by using compressed air.

(9) Ensuring that the rubber “0" ring is in place on the grease block (refer to photograph No. 6), mount grease block fitting onto surface of the radial gate arm using the 5/16-inch x 1-inch bolts. Use 5/16-inch lock washers to keep the bolts from vibrating loose.

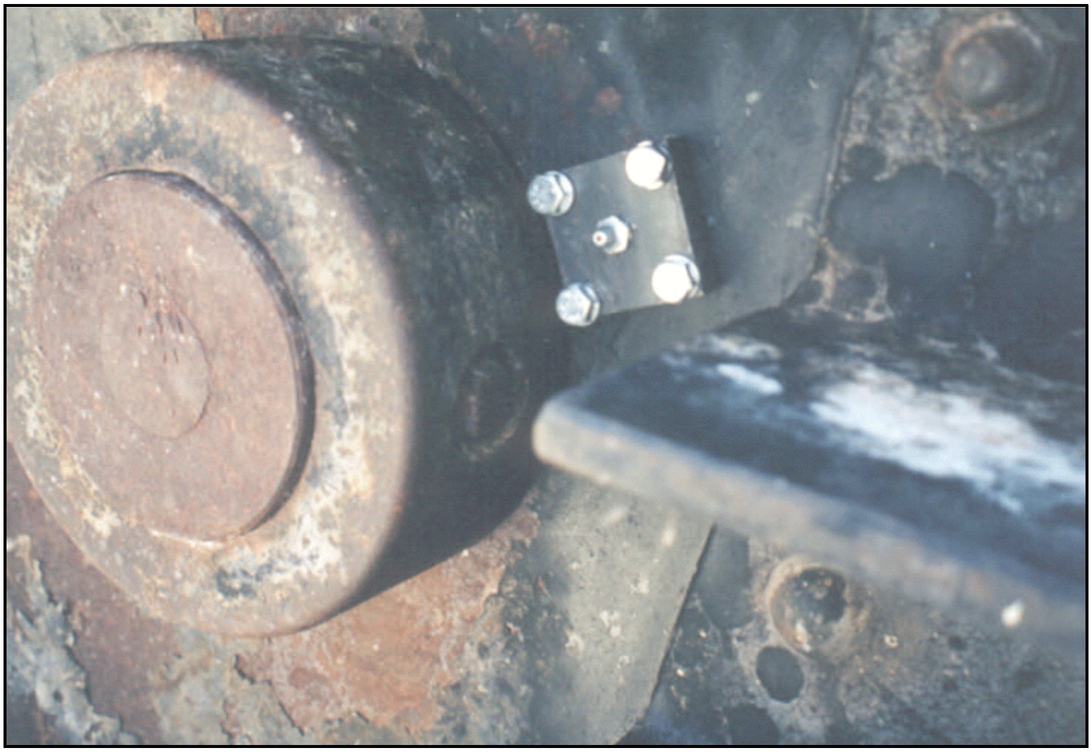
(10) Screw the 1/4-inch x 18 pipe thread grease fitting onto the grease block (refer to photograph No. 9).

(11) While operating the radial gates, pump grease into the installed grease-fitting block and watch for grease to appear around trunnion pin. At Agency Valley we used a long feeler gage to check for grease behind the safety collar or between the radial gate arm and the cast steel bearing.



Photograph No. 7.—Grease block fitting mounting and grease channel hole placement on radial gate arm.

Photograph No. 8.—The 3/16-inch extra length drill bit position for drilling to trunnion pin.



Photograph No. 9.—Installed grease block fitting on radial gate arm.

C. Results of Installing Grease Fitting Blocks on Radial Gate Arms

(1) A clamp-on ammeter was put across all radial gate hoist motor power leads, and the gates were operated prior to the grease being introduced to the trunnion pins. After the greasing procedure was completed, the amp probe was again put across the power lead to the radial gate hoist motors, and the gates were again operated. The readings were about the same for each gate before and after the grease was induced. Measurements with water against the gate may be more useful.

(2) A listening device was used (acetylene welding rod) during gate movement prior to the grease being introduced to the trunnion pins (one end of the rod was placed against the safety collar and the other end is placed against your ear). After the greasing procedure was completed, the listening device was again used, and there was a definite different sound that was generated. The sound of the gate seals rubbing on the concrete sidewalls was apparent in both instances, but the grinding sound that was heard without the grease was not heard after the grease was introduced.

(3) Once the 3/16-inch grease channel was filled, the grease could be seen coming out on both side of the radial gate arm. Because of the limited gate movement and no water on the gates, the grease did not go all the way around the trunnion pin, but

the grease did flow to the upstream 180-foot section of the trunnion pin. The general opinion is that when water comes against the gates, that pressure will be put on the upstream side of the trunnion pin to help spread the grease further around the trunnion pin.

D. Additional Considerations

(1) Almost every year the spillway gates at Agency Valley Dam are dry because of normal water drawdown, and a ladder could be set in the spillway floor to reach the grease fittings for lubrication.

(2) An alternative to this would be to install a pipe fitting in the grease-fitting hole and install a pipe so that grease could be introduced into the trunnion pin from the operating deck. This would allow greasing of the trunnion pins from the operating deck, and it would not be necessary to set a ladder on the spillway floor.

Mission

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