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Managing Water in the West

Water Operation and Maintenance Bulletin

No. 218

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Can Your Spillway Survive the Next Flood?

Learning Opportunity – Protective Coatings Hands-On Course/Training

U.S. Department of the Interior
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December 2006

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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For further information about the
Water Operation and Maintenance Bulletin, contact:

Jerry Fischer, Managing Editor
Bureau of Reclamation
Inspections and Emergency Management Group (86-68470)
PO Box 25007, Denver, CO 80225-0007
Telephone: (303) 445-2748
FAX: (303) 445-6381
Email: jfischer@do.usbr.gov

***Cover photograph** – Structural collapse*.

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Can Your Spillway Survive the Next Flood?

by John Trojanowski, P.E.[1]

Abstract

In the recent past there has been an emphasis on dam safety, and dams throughout the country are certainly much safer because of this effort. However, spillways often do not get as much attention as dams. A developing failure that is overlooked could result in a spillway failure during the next flood. There could be serious consequences associated with a spillway failure, and there is a growing need to raise the awareness of dam safety issues associated with spillways and the assessment of potential hydrologic failure modes. The ability to evaluate existing conditions and design deficiencies that can result in damage or failure of a spillway is a significant concern for dam owners and operators. Potential hydrologic failure modes include discharges that exceed spillway chute and stilling basin capacity, cavitation damage, foundation erosion, and hydraulic jacking during normal or flood operations. These failure modes can develop into a condition of headcutting leading to loss of reservoir. Methods for assessing the risk of failure resulting in loss of reservoir have been refined over the past several years.

Engineers and dam safety inspection staff should know how to identify and evaluate spillway failure modes during a review of these structures. A thorough evaluation is based on the examination of design and construction details as compared to current standards and observed field conditions. Often, signs of serious problems are overlooked by examiners because the observed damage appears to be minor in nature. Minor surface repairs are sometimes recommended when major modifications are actually needed.

One of the most significant challenges is identifying subtle signs that can indicate a major problem is developing. Past operational history may or may not be any indication of future performance. Design deficiencies may take some time to develop into a failure. An understanding of historic developments in spillway design can help spillway evaluators make assessments of likely design and construction details that were typical during the period of construction, even when as-built details are not available. Spillways on erodible foundations are of particular concern because failure can lead to a breach of the reservoir. This article will provide information that can be used to help identify potential spillway problems.

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[1] Civil Engineer, Waterways and Concrete Dams, Bureau of Reclamation, Denver, Colorado; e-mail: jtrojanowski@do.usbr.gov. This paper was also published by the United States Society on Dams for their 26th annual conference in San Antonio, Texas (May 1–5, 2006).

Historic Developments in Spillway Design

Over the years, spillway designs have gone from simple regulating structures with armored or concrete-lined downstream channels to state-of-the-art, high head, high velocity computer designed structures. Technology related to concrete design, hydraulic evaluation, hydrology, and foundation treatment and drainage has changed considerably over the past and will continue to change in the future. When evaluating an existing structure, it cannot be assumed that the design and construction practices of the past will meet today's requirements for a safe structure. Knowing when a spillway was constructed can be important when no design or construction details are available because the construction period can be compared to a timeline of historic developments.

Developments in Concrete Technology

Over the years, improvements in concrete technology have been applied to hydraulic structures. The Bureau of Reclamation (Reclamation) has been involved in considerable research that has resulted in widespread changes in technology. Between 1905 and 1910, the use of minimum reinforcement became common practice. However, early designers may not have considered all loading conditions. Reinforcement, consisting mostly of temperature steel, was typically placed near the surface or at the center of slabs and walls.

In 1929, basic principles for producing concrete materials were developed. This included improved methods of mixing, handling, and placing. Field process control techniques were found to be as important as water/cement (W/C) ratio in terms of concrete quality. These principles helped to mitigate concrete deterioration. After 1930, Reclamation required low W/C ratios and higher compressive strengths for concrete structures. Internal vibration for consolidation of concrete was made a common practice in about 1933, and in 1934, improved construction joint cleanup was common. Reclamation required low-alkali cement in virtually all concrete structures after 1942. After 1945, Reclamation required entrained air for virtually all concrete structures. By the late 1940s, Reclamation used pozzolans as a replacement for portions of cement and avoided the use of reactive aggregates. Alkali-Silica Reaction (ASR) reducing practices were implemented at that time. In the 1960s, waterstops were used on hydraulic structures. By 1967, deterioration due to sulfate attack was virtually eliminated. In the late 1970s, Reclamation's practice was modified to use about 20 percent Class F or N pozzolans as a replacement for some cement. By about 1980, virtually all Reclamation concrete structures were constructed with Class F pozzolans. Table 1 summarizes some of these important historic developments in concrete technology.

Table 1.—Historic concrete developments affecting spillway designs[1]

Time period	Key historic concrete development
1905–1910	Use of reinforced concrete became more common.
1929	Used basic principles for producing modern concrete materials.
1930	Air-entraining agents were introduced to improve concrete's resistance to freeze/thaw damage.
After 1930	Low W/C ratios and higher compressive strength became standard.
1933	Internal vibration of concrete was used.
1934	Improved construction joint cleanup was being used.
1940s	Portland Cement Laboratories perfect air-entrained concrete.
Late 1940s	ASR reducing practices were implemented.
1945	Reclamation’s specifications required entrained air.
1960s	Use of waterstops was common.
1967	Sulfate attack was virtually eliminated.
1980s	Superplasticizers were introduced as admixtures.

[1] Most of the information included in this table was provided by John LaBoon, Waterways and Concrete Dams, Bureau of Reclamation, Denver, Colorado.

Developments in Hydraulic Evaluation of Spillways

Over the years, Reclamation and others have completed numerous hydraulic model studies and research studies related to spillway designs. These studies addressed issues such as spillway discharge capacity, energy dissipation in stilling basins, cavitation damage potential, and stagnation pressures at offset joints. Spillway designs have improved significantly as a result of these studies. Many of the resulting developments have been implemented within the engineering community, but it is not likely that spillways constructed earlier would have incorporated these developments. For many years, experienced engineers involved in the design of spillways have been aware of methods for determining discharge coefficients for spillway crests and how to size various types of stilling basins. Reclamation and others have produced numerous publications on these subjects. Developments related to cavitation damage and the use of waterstops to reduce stagnation pressures and seepage are more recent, and many spillways that are still in operation may not have incorporated these developments.

Cavitation

After 1941, based on the cavitation damage experienced by Hoover Dam Spillway and the subsequent investigations, very stringent concrete surface finishes-tolerances were required by Reclamation for flow surfaces subjected to average flow velocities greater than 75 feet per second (ft/s). In 1961, the effectiveness of aeration to mitigate cavitation was demonstrated for the Grand Coulee Outlet Works. By 1967, the first installation of a spillway aerator was done by Reclamation at the Yellowtail Dam Spillway. In 1983, reliance on aerators to prevent cavitation damage occurred with the Glen Canyon Dam Spillways. By 1987, concrete surface tolerance and finishes were separated in Reclamation designs, and tolerance requirements were associated with cavitation indices.

Waterstops

For earlier designs, metal waterstops were used by Reclamation in concrete dams and in spillway crests to prevent leakage of reservoir water through contraction joints. Although not all spillway crest structures were thought to need waterstops, excessive leakage was often observed in gated spillway crest structures. Early designers did not always consider problems related to seepage through joints in spillway chutes or stilling basins. However, after about 1970, waterstops were regularly used in all flow surface joints to prevent uncontrolled seepage into or out of the foundation. By 1976, Reclamation identified potential for stagnation pressures to develop at joints that are offset into the spillway flow and started to implement defensive measures. The failure of Big Sandy Dam Spillway in 1983, and subsequent evaluation, helped define the stagnation pressure failure mode. Research to date has been limited, but it has helped designers understand problems related to stagnation pressures.

Identification and Evaluation of Failure Modes in Spillways

As stated above, the focus of this article is on hydrologic failure modes for spillways. There are five notable hydrologic spillway conditions that can lead to failure modes during a spill event: (1) existing structural damage that can compromise the spillway, (2) flows that exceed the spillway capacity, (3) cavitation damage, (4) significant stagnation pressures leading to either hydraulic jacking or structural collapse, and (5) groundwater related erosion. Mechanical gate failures are also possible, but will not be discussed here. Reclamation has a Comprehensive Facility Review (CFR) program for their dams. Other organizations may have similar programs. Each Reclamation dam undergoes a comprehensive review every 6 years. Hydrologic failure modes are evaluated during the CFR. Recently, there has been a focus on spillway failure modes. Additional failure modes related to normal and seismic loading conditions are also evaluated. The hydrologic failure modes related to spillways are discussed further.

Existing Structural Damage

Most existing structural damage is easily observed during a site inspection unless the damaged areas are inaccessible and require special inspection (such as an underwater dive inspection). Spillway damage may have occurred as a result of a wide range of problems:

- Previous spillway flows that have initiated one of the other four failure modes
- Deterioration of the structure
- Foundation problems
- External loading

The possibility that observed structural damage can affect the performance of the spillway should be given serious consideration. If the damage significantly increases the risk of failure, the owner and/or engineer will want to determine the cause of the damage and develop a program to repair the damage, modify the structure, and/or impose operating restrictions to avoid uncontrolled release of the reservoir during a spill. Flooding resulting in spillway failure can occur while a spillway is in a state of disrepair.

Some structural damage is not obvious during an inspection. Indicators of structural damage may be subtle and may go unnoticed to the untrained eye. Cracking, spalling, or offsets at structural joints may appear to be minor and attributed to temperature affects or minor foundation movements. However, these could also be indicators of excessive structural loading, settlement, foundation erosion, frost heave, ASR, delamination of concrete at the reinforcement mat, or other underlying problems. Design loads should be compared to the actual or suspected loading conditions to determine if the structure was under designed. Often, older structures do not have adequate strength for loading conditions caused by earthquakes, saturated backfill, high differential uplift pressures, dynamic pressure fluctuations, or foundation or ground movements. The concrete and reinforcement may not have been designed to current standards for the expected loading. Due to the age of the structure, advances in concrete technology may not have been employed. Drainage behind or beneath the structure may not be adequate or may be damaged. The drains, if present, may not be properly filtered to prevent foundation erosion. Foundations may not have been adequately designed to prevent damage due to settlement, frost heave, or swelling soils. The possible cause of observed structural damage should always be investigated through study of available design and construction documentation and field investigations when needed. Simply repairing surface damage may not improve the safety of the structure.

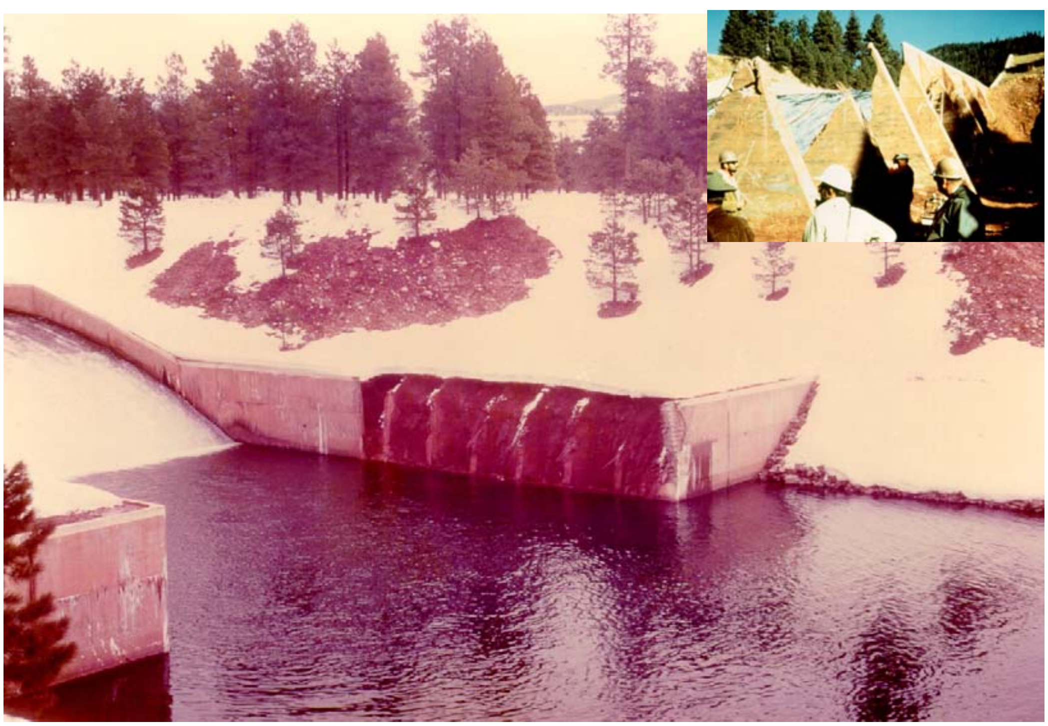
Existing structural damage – deterioration (Scofield Dam Spillway).

Existing structural damage – offsets and spalling (McPhee Dam Spillway).

Existing structural damage – cracking (Hyrum Dam Spillway).

Existing structural damage – cracking and spalling (Bull Lake Dam Spillway).

Existing structural damage – delamination (Deer Creek Dam Spillway).



Existing structural damage – collapse (Vallecito Dam Spillway).

Spillway Capacity

Typically, a spillway design capacity is known or can be determined through engineering evaluation. The design of many dams, especially in the Western United States, may be based on limited hydrologic data. Updated hydrology can result in flood discharges that exceed the design spillway capacity. Hydrologic evaluations may focus on the ability of the waterways to pass floodflows without overtopping the dam. However, while a spillway gate or inlet structure may be capable of passing flows that exceed the design discharge, the spillway chute or stilling basin may not fare well under these conditions. Water surface profiles for various flows, including those flows exceeding the design capacity, will aid in the evaluation of this failure mode. One should pay close attention to areas of rapidly varying flow, including changes in slope or cross section.

Spillway capacity exceeded (El Guapo Dam Spillway).

It is important to evaluate flow depths and velocities in spillway chutes, stilling basin capacity, hydraulic jump development, sweepout conditions, and the downstream tailwater. High flows may cause spillway walls to be overtopped, leading to erosion of backfill and possible collapse of the structure. Higher flow depths can also collapse a structure designed for much lower flow. Stilling basin walls can be overtopped by high flows. Even if the stilling basin can contain a hydraulic jump, the sweepout conditions at the upstream end can result in unusual differential loading with uplift pressures equal to tailwater on the outside of the structure and low flow depths on the inside. Sweepout or a hydraulic jump that develops beyond the end of the stilling basin can result in excessive erosion and undermining of the structure. If damaged, the stilling basin can erode and initiate undermining of the chute, which can initiate headcutting. Various design aids, including Reclamation's Engineering Monograph (EM) No. 25 [1] can be used to evaluate stilling basin capacity.

Spillway capacity exceeded (El Guapo Dam Spillway).

Cavitation Damage

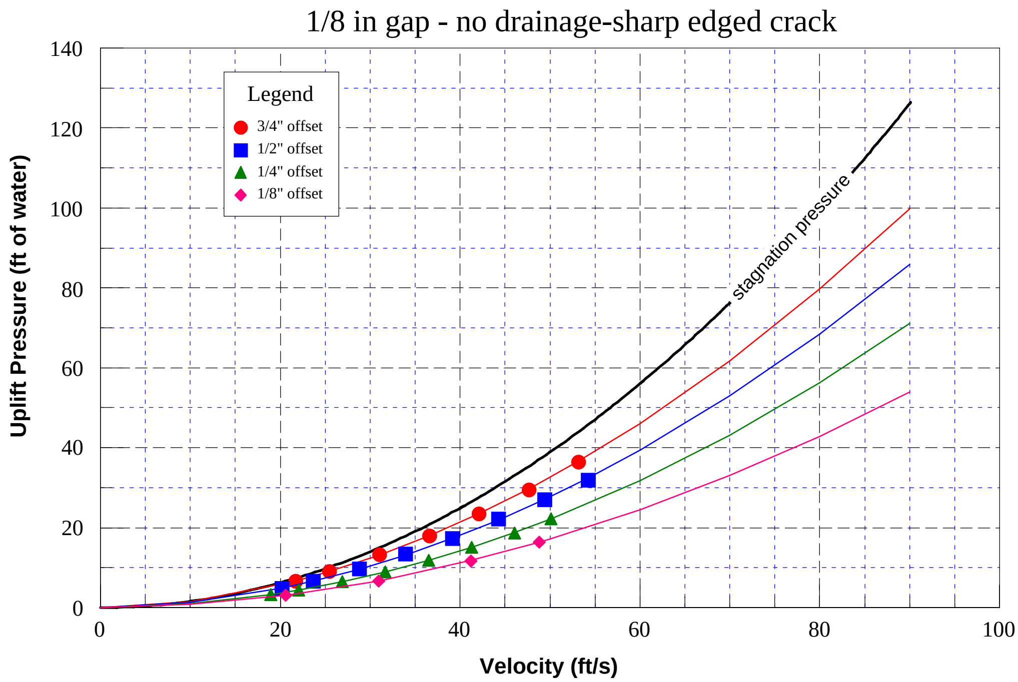
The potential for cavitation damage can be determined by using design aids such as Reclamation's EM No. 20 [2]. A water surface profile for various flow conditions is needed to evaluate cavitation damage potential. If unchecked, cavitation damage can erode through a spillway lining, compromising the foundation below. Large holes have developed in hard rock foundations at Hoover and Glen Canyon Dams after the concrete liner was damaged by cavitation and the foundations were exposed to high-velocity flows. Lower velocity flows could be more damaging in softer foundations due to greater potential for foundation erosion. Typically, spillways that have operated at relatively high flows for extended periods will have visible signs of cavitation damage if cavitation is a significant concern. However, spillways that have only

Cavitation damage (Glen Canyon Dam Spillway).

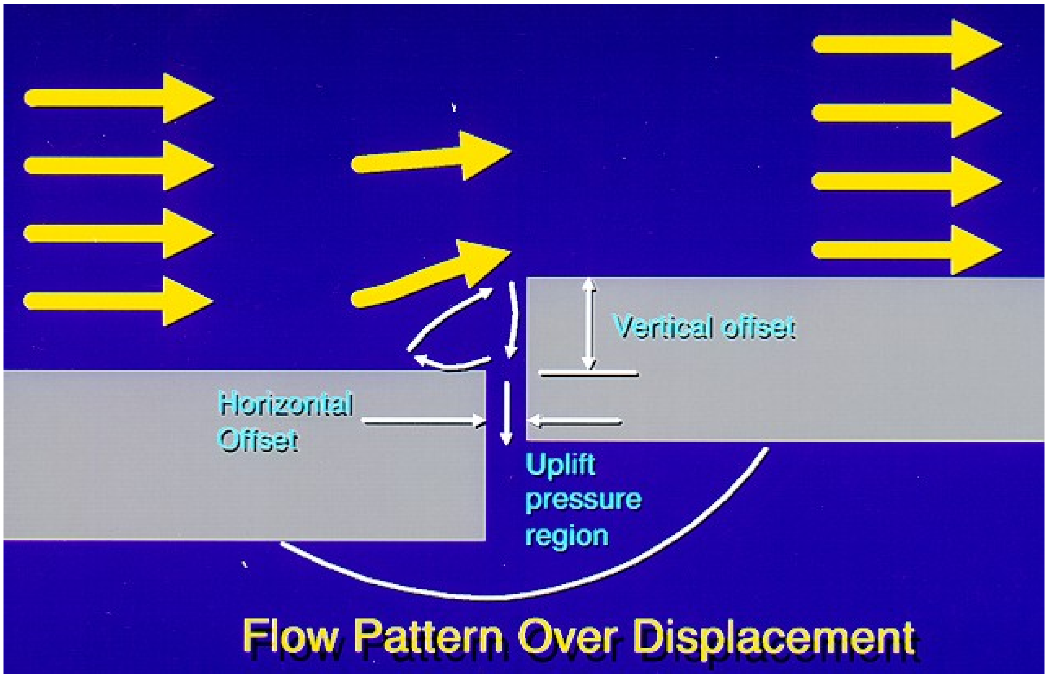
operated at limited flows may not show signs of potential future damage. It is important to understand the operating history and cavitation potential before ruling out this failure mode based on visual observation.

Stagnation Pressures

Two failure mechanisms, as described by Trojanowski [3], can produce this failure mode. These are structural collapse due to foundation erosion and hydraulic jacking due to excessive stagnation pressures. Research by Reclamation [4, 5] can be useful in determining stagnation pressures at offset joints projecting into the flow for flow velocities up to 15 ft/s. Extrapolation of these data [3] indicated that much higher stagnation pressures may be possible for the higher flow velocities that might be expected on steep spillway slopes. However, Reclamation currently has not performed any research that would verify this assumption. Additionally, the research to date [4] does not include any measurement of flow through an offset joint or crack, although some studies indicate that these flows could exceed the capacity of a typical spillway under drains designed to control seepage. This kind of information would be helpful in determining erosion and uplift potential resulting from offsets into the flow.



Stagnation pressure at offsets 1/8" crack, no drainage flow, offsets into flow.



Stagnation pressure.

Structural Collapse

Structural collapse occurs when the foundation is exposed to flowing water that causes significant erosion and a portion of the spillway liner settles or collapses into the resulting void. The presence of erodible foundation materials will contribute to this potential failure mode. A structural collapse can expose foundation materials to high-velocity flows, initiating a potential headcutting failure.

Significant consolidation of foundation materials beneath the concrete after construction can result in cracking or offsets at joints. Voids caused by settlement, frost heave, or other conditions can result in open flow channels in the foundation. Lack of waterstops, cutoffs, and other features to control seepage into the foundation can result in free flowing water. Foundation materials can erode through these channels. Unfiltered drains, open joints, or cracks in concrete provide an exit point for flowing water. Water flowing from drains, joints, or cracks can be monitored if they are visible and accessible. A discolored discharge or deposit of sediment near drain outfalls could be signs that this failure mode is developing.

Structural collapse.

A well-designed filtered drainage system can reduce the potential for erosion. Additionally, waterstops through concrete joints, keying of joints to prevent offsets, and adequate reinforcement can reduce the risk of this failure mode. As discussed above, waterstops, which could prevent flows in the chute from entering into the foundation, were not generally used until about the 1960s. Many older spillways have drainage systems consisting of clay tile pipe in a gravel envelop. These drains generally do not meet modern filter criteria.

Reinforcement of earlier spillways often consisted of a single layer of reinforcement near the exposed surface. This reinforcement could withstand very little bending. However, when voids develop in a foundation, there may be a period when the invert slab or chute wall footing temporarily bridges the void. Initially, minor cracking may not appear to be significant. Once the shear or bending capacity is exceeded, the structure can experience severe cracking or sudden failure. Loading of the structure and the potential for foundation erosion will increase during a spill, making failure more likely.

Structural damage – foundation materials discharging from drains (Hyrum Dam Spillway).

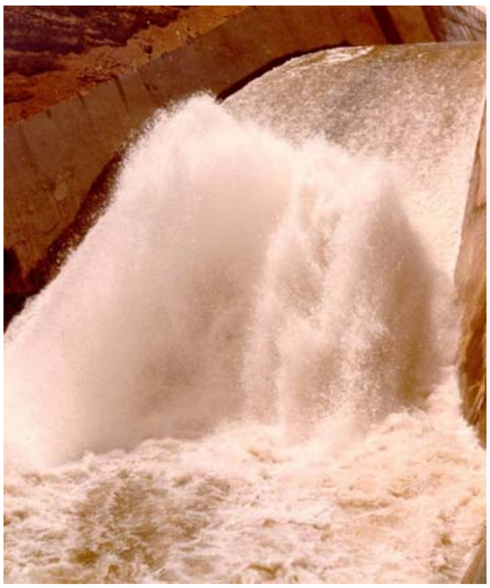
Temporary bridging of foundation voids occurred at Hyrum Dam Spillway near Logan, Utah. The potential for voids beneath the invert slab was not identified during early inspections of the Hyrum Spillway because the visual signs of a design deficiency were not well understood. Observed surface cracking was thought to be minor, and further investigation was not recommended. During a 2003 inspection, the surface cracking was again observed in the invert slab. The spillway design details had been carefully evaluated prior to the inspection, and it was concluded that there was significant potential for foundation erosion. Once this potential failure mode had been identified, the cracking pattern provided visual indication that voids were possibly forming in the foundation. Discolored discharge from the drain outfall was observed during a test flow. Subsequent investigations that included drilling through the spillway slab revealed the voids in the foundation, and repairs were made.

Structural damage – foundation materials discharging from drains (Bull Lake Dam Spillway).

Hydraulic Jacking

Conditions contributing to this failure mode include concrete cracking or offsets at joints due to settlement, deterioration of joints (freeze-thaw or other) that produce offsets into the flow, lack of waterstops and/or keys at joints in the concrete, and high-velocity flows in the spillway chute. Flows passing over offsets in spillway liners can induce high uplift pressures that can lift concrete slabs. This occurs when offsets are projecting into the flow and adequate drainage capacity is not present. Once hydraulic jacking occurs, the increased offsets caused by jacking will allow high volume flows to enter the foundation, causing erosion. Model testing by Reclamation [4] has provided some guidance for evaluating this condition. However, this testing was limited to lower flow velocities (up to 15 ft/s). Extrapolation of these data [5, 3] has indicated that uplift pressures may increase significantly with higher velocities. Reclamation plans more testing to include higher velocities and flow rates into joints.

Two Reclamation spillways have documented failures that resulted from hydraulic jacking [5]. Dickenson Dam Spillway in North Dakota failed during a 4,000 ft^3/s spill in 1954 that had an average flow velocity of 21 ft/s. The failure occurred after the underdrains were plugged due to freezing, and erosion occurred in the soft sandstone and shale foundation. Big Sandy Dam Spillway in Wyoming failed during a discharge of 400 ft^3/s in 1983 that produced an average velocity of 31 ft/s. Flow was entering the foundation through spalled and open joints. It is believed that one of the Big Sandy underdrains was plugged with debris during the spill. The uplift pressure in the undrained foundation caused failure of anchor bars grouted into a soft sandstone foundation. Neither of these spillway failures resulted in a breach of the reservoir because the foundation was somewhat resistant to erosion and headcutting did not initiate.



Hydraulic jacking (Big Sandy Dam Spillway).

Erosion occurred in the soil foundation of Hyrum Dam Spillway during yearly runoff flows. Flow velocities in the chute exceeding 50 ft/s occurred occasionally prior to modification of the spillway. Most flows into the foundation exited through the unfiltered clay tile underdrains, causing significant erosion. However, hydraulic jacking failure did not occur because the drain capacity was not exceeded. If the drains at Hyrum had become plugged like those at Dickenson and Big Sandy, hydraulic jacking could have occurred. Because the Hyrum Dam Spillway foundation is highly erodible, a hydraulic jacking failure would have resulted in headcutting and possible breach of the reservoir. Unlike the other two spillways, the signs of a developing failure at Hyrum were better understood in 2003, and action was taken before conditions progressed to failure. Hyrum Dam Spillway was modified in 2004. The spillway safely passed record flows with velocities approaching 60 ft/s resulting from the 2005 spring runoff.

Groundwater Related Erosion

Flowing water in the foundation does not always originate in the spillway chute during a spill event. Seepage in the foundation can originate from the reservoir, groundwater, or from surface runoff due to local precipitation. Generally, this will not produce problems in well-drained foundations with adequate filtering of drainage materials. Many spillways have been designed without adequate drainage. Unfiltered drains such as the clay tile pipe in a gravel envelop at Hyrum Dam Spillway (and many others) provide an open path for erosion of foundation materials. Unfiltered open joints in the spillway can also provide a path for erosion into the spillway chute. Erosion of foundation can produce structural collapse similar to the collapse that results from stagnation pressure related erosion, except that a spillway discharge is not necessary for this condition to develop. Poorly consolidated foundations may also settle when exposed to groundwater. This condition can create seepage paths and/or structural damage.

Groundwater related erosion (Hyrum Dam Spillway).

Signs of groundwater related erosion are discolored discharge in drains, seepage through joints and cracks, and accumulations of foundation materials near these seepage sources. Signs of foundation movement, settlement, or voids adjacent to the structure may also indicate erosion is occurring.

Identifying Potential Failure Modes

Identification of the potential failure modes described above can be done in four stages. The first stage is to become familiar with the design and construction details. It is important to gather as much information as possible to make an assessment. Design drawings and specifications along with geology, construction, and laboratory reports can be very useful if they are available. Climate and temperature data are also useful. However, some of this information may not be available for older structures. Even if available, geology reports for the dam may not include details of the spillway foundation. When there is a lack of data, evaluation will be based on inferred conditions and/or field investigations. Comparing the period of construction to the timeline of historic developments discussed above can improve understanding of possible as-built conditions. Of particular concern are details of the joints, cutoffs (for erosion and seepage), drainage, filtering, reinforcement, and waterstops.

The second stage is analysis. The design capacity of a spillway may be given or computed. Updated hydrology should be compared to the design floods. Flood routing studies may be needed to determine the spillway discharge resulting from various floods entering the reservoir. Water surface profiles can help determine when spillway and stilling basin capacities are exceeded, flow velocities, and cavitation potential. If conditions exist that can result in the foundation being exposed to stagnation pressures, the water surface profile results can give an indirect indication of the magnitude of potential stagnation pressures. Structural analysis can help determine if the structure can withstand the flood loading and potential high uplift pressures.

The third stage involves site inspection. To an untrained eye, minor offsets or damage may not appear to be significant. However, they can be signs that foundation problems are developing. Knowing how the spillway was constructed and where drain outfalls and other potential problem areas are ahead of time will help in the evaluation during visual observations. Knowing the hydraulic conditions and operating history can help when identifying cavitation damage or signs of erosion damage. When a potential problem is identified, it should be evaluated further through field investigations. Voids found along the sides of Hyrum Dam Spillway were being used by burrowing animals. It may have appeared that these voids were caused by these animals, but further investigation showed that they were actually caused by erosion.

The fourth stage of investigation involves field exploration. Although this can be expensive, it should be done when developing failure modes are suspected. Too often inspectors have recommended repair to damaged areas without further investigation. Foundation damage may not always be apparent from surface observation. Some tools to consider are geologic mapping and investigation, test flows to observe the performance of drains and other features, sounding to locate drummy concrete, ground-penetrating radar, drilling to sample materials and/or locate and investigate potential voids, and down-hole cameras to investigate drains or drilled holes.

Leaving out one or more of these stages could result in major problems being overlooked. Repairing apparent surface damage may only mask a significant underlying problem that needs more immediate attention.

Evaluating Risk

Although portions of the spillway such as a chute wall, invert slab, or stilling basin may fail during a spill, there may not be loss of life or significant property damage if the reservoir can still be controlled and dam failure or uncontrolled release of the reservoir prevented. Reclamation incorporates a risk analysis process that includes event trees to determine the sequence of events that would be necessary to cause uncontrolled release of the reservoir and/or loss of life downstream. Guidelines are used to determine if the risks justify corrective actions [6]. While uncontrolled release of the reservoir and loss of life are significant concerns, the potential loss of a spillway may be a significant economic concern. Failure of a low risk spillway may be avoided by making necessary modifications, but this may be dictated more by available funding.

The first step in determining risk is to determine the loading and load frequency that would result in a potential failure, such as the flood that initiates a failure mode. The next step is to identify the initiating failure mode or failure modes and the sequence of events necessary to cause failure. Next, evaluate the steps and time needed to go from initiating a failure to headcutting the reservoir. If failure is indicated, the final step is to determine the consequences of a failure in terms of loss of life and/or downstream damage. If the risks are found to be high enough, a corrective action can be justified.

Conclusions

Evaluation of hydrologic failure modes for a spillway is a four step process. Following these steps can mean the difference between detecting and correcting a potential failure mode before it develops or failure of a spillway during a flood.

1. *Evaluation*: Evaluate the design and construction using available documentation and/or a timeline of developments.

2. *Analysis*: Analyze hydraulic and structural capabilities and identify failure modes.

3. *Inspection*: Look for signs of developing failure modes.

4. *Investigation*: Field investigations can verify suspected problems that are not visible during an inspection.

References

[1] Bureau of Reclamation, Engineering Monograph No. 25, "Hydraulic Design of Stilling Basins and Energy Dissipators," Denver, Colorado, eighth printing, May 1984.

[2] Bureau of Reclamation, Engineering Monograph No. 42, "Cavitation in Chutes and Spillways," Denver, Colorado, 1990.

[3] Trojanowski, J., "Assessing Failure Potential of Spillways on Soil Foundation," Association of State Dam Safety Officials Annual Conference, Phoenix, Arizona, September 26–29, 2004.

[4] Johnson, P.L., "Research into Uplift on Steep Chute Lateral Linings," Bureau of Reclamation, July 15, 1976.

[5] Hepler, T.E. and P.L. Johnson, "Analysis of Spillway Failure by Uplift Pressure," Bureau of Reclamation, prepared for ASCE National Conference on Hydraulic Engineering, Colorado Springs, Colorado, August 8–12, 1988.

[6] Bureau of Reclamation, "Guidelines for Achieving Public Protection in Dam Safety Decision Making," Denver, Colorado, June 15, 2003.

Learning Opportunity – Protective Coatings Hands-On Course/Training

The Protective Coatings Hands-On Course will be presented by the Materials Research and Engineering Laboratory. Following is a course description, including the dates and tuition.

Protective Coatings Hands-On Course – This 2-day course offered on February 27 and 28, 2007, will familiarize students with the latest coating application and inspection techniques related to maintenance and repair of infrastructure. Topics will include:

- Surface preparation
- Application and inspection methods
- Coating technology
- Standards
- Overcoating
- Common design flaws

The class will emphasize hands-on experience, enabling participants to prepare steel panels and apply coatings and to perform both destructive and non-destructive tests on these panels.

The tuition for each participant will be approximately $700. This cost is subject to change and may increase or decrease depending on the number of participants. The training session will be held at the Denver Federal Center, building 56, room 1730. Class will begin at 8:00 a.m. on Wednesday, February 27, 2007, and conclude at 5:00 p.m. on Thursday, February 28, 2007.

To register for this training session, Denver or Washington employees will need to complete a nomination form. Regional employees will need to submit an approved training form (SF-182). Both forms must be submitted via fax no later than January 31, 2007, to Thisha Kenney, Training Coordinator, Human Resources Division, 303-445-6348. Employees selected to attend this course will be notified and provided logistical information shortly after this date. Participants who are selected for this course, but who cancel without a substitute, will be charged full tuition.

Another course will be offered in October 2007.

Questions can be directed to Thisha Kenney at 303-445-2646 or e-mail: <tkenney@do.usbr.gov>.

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.

The purpose of this bulletin is to serve as a medium of exchanging operation and maintenance information. Its success depends upon your help in obtaining and submitting new and useful operation and maintenance ideas.

Advertise your district's or project's resourcefulness by having an article published in the bulletin—let us hear from you soon!

Prospective articles should be submitted to one of the Bureau of Reclamation contacts listed below:

Jerry Fischer, Bureau of Reclamation, ATTN: 86-68470, PO Box 25007, Denver, CO 80225-0007; (303) 445-2748, FAX (303) 445-6381; email: jfischer@do.usbr.gov

Vicki Hoffman, Pacific Northwest Region, ATTN: PN-3234, 1150 North Curtis Road, Boise, ID 83706-1234; (208) 378-5335, FAX (208) 378-5305

Steve Herbst, Mid-Pacific Region, ATTN: MP-430, 2800 Cottage Way, Sacramento, CA 95825-1898; (916) 978-5228, FAX (916) 978-5290

Albert Graves, Lower Colorado Region, ATTN: BCOO-4846, PO Box 61470, Boulder City, NV 89006-1470; (702) 293-8163, FAX (702) 293-8042

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