Session XVI

INSPECTION OF SPILLWAYS, OUTLET WORKS AND MECHANICAL EQUIPMENT

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INTRODUCTION

Spillways, outlet works, and the associated mechanical equipment are essential to the continued safety of an existing dam. The function of spillways is to pass normal and/or flood water in a manner that protects the structural integrity of a dam. Outlet works are the normal means of releasing water impounded by a dam. Proper operation of a dam in an emergency situation may depend on the ability of its outlet works and gated spillways to make releases. Improper operation of the mechanical equipment can inhibit releases and result in dam failure.

Importance of Spillway and Outlet Works Inspection

Most spillway and outlet works structural defects and deterioration develop progressively. Before such conditions become serious, a trained, experienced dam inspector can find evidence of defects and potential problems. Periodic inspection may reveal trends that indicate more serious problems are developing.

Some problems arise suddenly. Full-capacity use during storms, flooding, or high-velocity releases can cause serious damage. For that reason, special inspections should be conducted after such events, or after seismic activity or other circumstances that may have affected the spillway and outlet works structures.

Because some mechanical equipment is used very infrequently (often in emergency situations only), regular inspections must be conducted to ensure that the equipment will function when needed. Since a large portion of this equipment is exposed to the elements, operating and structural problems can develop that may only be discovered through periodic inspections and testing.

Functions of Spillways and Outlet Works

Distinguishing Spillways From Outlet Works

No definite dividing line can be drawn between outlet works and spillways. In general, a pressurized, gate- or valve-controlled conduit that carries water through a dam is considered an outlet works rather than a spillway.

Spillways and outlet works may share many features, and can even be combined into one structure. A dam created with mine tailings, for example, often has only a conduit through the dam for passing water. On more elaborate dams, a combined structure may have separate outlet works and spillway portions, with each portion having separate means of intake and control.

Different organizations may vary in labeling these combined structures, but inspection of outlet works is very similar to inspection of spillways.

<u>Spillway Use Classifications</u>

Spillways often are classified according to the expected frequency of use. The following common classifications may be used:

- Frequent Use: Primary, Principal, or Service spillways.
- Infrequent Use: Auxiliary or Emergency spillways.

For the purposes of this discussion, primary or principal spillways are used for normal operation and are the spillways used first during flood flows. Primary spillways are constructed of durable material, and are designed to withstand frequent use without significant damage to themselves or the dams.

Service spillways are primary spillways used to regulate reservoir releases in addition to, or in lieu of, an outlet works.

Secondary spillways, also called emergency or auxiliary spillways, are designed to operate only during exceptionally large floods. Secondary spillways are designed to provide additional protection against overtopping of the dam and are intended for use under extreme conditions such as extreme flooding or misoperation or malfunction of a service spillway or other emergency conditions.

<u>Outlet Works Purpose Classifications</u>

Outlet works can be classified using three different criteria: purpose, structural configuration, and hydraulic operation.
Typical purposes served by an outlet works include:

- Normal release for irrigation, hydroelectric power generation, and municipal and industrial use
- Stream bypass for minimum release requirements
- Reservoir drainage

A particular outlet works may serve more than one of the purposes listed above. The size, location, type, and design of the outlet works are influenced by the purpose(s) it is intended to serve.

Structural Configuration Classifications

Outlet works can also be classified according to the structural configuration of their dominant feature, the waterway. An outlet works waterway can be:

- Conduit through a concrete dam.
- Conduit through an embankment dam.
- Carrier pipe or penstock resting on supports within a larger conduit.
- Exposed pipeline or penstock carried on supports.
- Conduit within a tunnel excavated through in situ material, usually away from the dam.

Hydraulic Operation Classifications

An outlet works can also be classified according to its hydraulic operation. It may be gated or ungated, and flow as a pressure pipe or a free-flow pipe. The location of regulating gates or valves is the major factor determining the hydraulic characteristics of the outlet works. Depending on whether gates are upstream, midstream, or downstream, a closed conduit or tunnel may flow under pressure for all or part of its length, or it may be a free-flow waterway. Pressure characteristics of a waterway are also influenced by the geometry of the intake and conduit.

Combinations of Spillways and Outlet Works

Spillways may be constructed adjacent to one another, in combination with an outlet works. Spillway and outlet works configurations vary so widely that the many different combinations would be difficult to list.

Consequences of Spillway or Outlet Works Failure

There are two types of spillways and outlet works defects that cause dam failures and accidents:

- Inadequate Capacity. The primary cause of most dam failures is overtopping of embankment dams because of inadequate spillway and outlet works capacity. These failures are one reason why a majority of unsafe dams are considered unsafe not because of structural defects or deterioration, but because of inadequate spillway capacity.

- Structural Defects and Deterioration. Historically, most dam failures and accidents related to spillway or outlet works structural defects and deterioration fall into the following categories:

    - Erosion of embankment material. (This category does not include erosion from overtopping or failure of slope protection).

- Deformation. (Deformation results from settlement, faults, or other causes).

- Deterioration. (Corrosion and cracking are the most common types of deterioration). .

In addition, spillways and outlet works often are involved in failures and accidents attributed to:

- Overtopping. Most overtopping incidents result from inadequate spillway capacity, as mentioned previously. But in some cases overtopping and subsequent failure of dams have been caused by blocked or inoperative spillways and outlet works.

- Embankment seepage erosion. Seepage erosion often begins along the outside of outlet works pipes.

SPILLWAY AND OUTLET WORKS COMPONENTS

Spillways and outlet works can each be described as a series of components, with each component serving a role as the flow of water moves downstream.

Spillway Components

Five components may be present in a spillway. The following chart lists the components and describes their functions.

Component	Function
Entrance Channel	Conveys water from the reservoir to the control section.
Control Section	Regulates volume of releases.
Water Conveyance	Conveys flows from the control section over, through, or around the dam: may be a channel, conduit, or tunnel.
Energy Dissipation Section	Reduces the energy and velocity of the flowing water.
Return Channel	Conveys discharges to the natural stream channel downstream from the dam.

The control section is the only component common to all spillways. Many spillways do not have an entrance channel or return channel. Also, not all spillways have an energy dissipation section. A few spillways drop water directly from the control section to energy dissipators, a return channel, or a natural streambed.

Entrance channels, discharge channels, and return channels all are open channels located at different points in a spillway. The entire spillway may be an open channel.

Closed spillways have a conduit or tunnel to convey water from the control section.

Spillways may be unlined (surfaced with vegetation, or excavated in earth or rock), or the components may be lined with concrete, riprap, or various other materials.

Merged-Component Spillway Designs

Some spillways cannot be described just in terms of the five spillway components. Instead, typical forms or designs are used to describe these types of spillways. Various features such as trash booms, trashracks, and gates may be added to these spillway designs to supplement their operations.

Tube Spillways

Culverts and siphon spillways are pipes or tubes running under or through the dam.

Drop Spillways

Drop spillways allow water to fall freely into an energy dissipation section, return channel, or streambed. The drop spillway structure incorporates an overflow crest, and usually a wall to carry discharge, as well as a floor or apron, often with energy dissipating devices. Drop spillways are constructed in a variety of shapes.

Outlet Works Components

The following chart shows the six components that may be present in an outlet works, and the functions of those components.

Component	**Function**
Entrance Channel	Conveys water from the reservoir to the intake structure.
Intake Structure	Serves as an entrance to an outlet works.
Gate Or Valve Housing	Supports or encases a gate or valve which regulates outlet works releases.
Conduit	Conveys water through or around a dam.
Energy Dissipation Section	Reduces the energy and velocity of the flowing water.

Return Channel	Conveys discharges to the natural stream channel downstream from the dam.

The sequence of the gate or valve housings and conduit is not clear-cut. Typically, some conduit may be located upstream of a gate or valve housing, with additional conduit downstream of the control component as well.

GENERAL PROBLEMS AND DEFICIENCIES

Some general problems may occur throughout a spillway or outlet works. These concerns include:

- Common material problems
- Obstructions
- Differential movement
- Misalignment
- Foundation/backfill problems
- Seepage
- Poor drainage

CONCRETE PROBLEMS COMMON IN SPILLWAYS AND OUTLET WORKS

Spillways and outlet works experience the entire range of possible concrete problems, but conditions especially worthy of note are:

- Cracking
- Surface defects
- Concrete deterioration: cavitation
- Concrete deterioration: erosion
- Leaking Joints
  - Inadequate or damaged waterstops
  - Other joint problems

Cracking

All concrete is subject to cracking, which is usually the first visible sign of concrete distress, but not all cracks are serious. However, cracking should be monitored because cracks can provide openings in the concrete that allow other types of deficiencies to develop.

Generally speaking, most cracks will fall into the "to-be-monitored" category--cracks that have been monitored in the past and should be measured and documented. A good ongoing record is necessary in order to identify a significant change or trend. New, severe, or extensive cracking and sudden changes warrant action. The following are a few inspection guidelines:

- For cracks that have been monitored and documented before, an inspector should take measurements and document any changes. Based on the trend noted for a particular crack, the interval between measurements may be increased or appropriate instrumentation may be recommended.

- Prominent cracks or cracking over large areas should be measured and documented. In these cases, too, more frequent measurements or installation of instrumentation may be advisable.

- Extensive new cracking, a crack survey should be considered to thoroughly document all cracks in the structure and their characteristics.

- If a major new crack is observed, or one whose characteristics have changed drastically from the previous inspection, a qualified engineer should make an assessment of the situation as quickly as possible.

- Cracks indicating movement that might be detrimental to the structure or to equipment operation (e.g., misalignment of gates that impedes gate operation and water release), should be evaluated by a qualified engineer.

- Repairs should be recommended for cracks which have excessive amounts of water flowing through them which cannot be handled by the drainage system.

Surface Defects

Surface defects are concrete deficiencies that are not progressive in nature; that is, they do not necessarily become more extensive with time. They may include:

- Shallow deficiencies in the surface of the concrete.
- Textural defects resulting from improper construction techniques.
- Localized damage to the concrete surface.

When surface defects in the concrete are observed, an inspector should:

- Record their nature and location.
- Note the need for prompt repair of defects that might lead to more extensive deterioration (e.g., by allowing water to enter the concrete mass).

Among the most common types of surface defects are honeycomb, stratification, evidence of form slippage, stains, and impact drainage.

<u>Honeycomb</u>

Honeycomb is a void that is left in the concrete when the mortar fails to fill the spaces between the coarse aggregate particles effectively. Honeycomb is caused by poor construction practices, such as inadequate concrete mixing, segregation due to improper placement practices, or inadequate vibration after placement in the forms.

Stratification

Stratification is the separation of overly wet or over-vibrated concrete into horizontal layers, with increasingly smaller material concentrated toward the top. Stratification can result in concrete of nonuniform strength, weak areas, and disbonding of lift lines.

Form Slippage

Form slippage occurs when construction forms lack sufficient strength to withstand the pressure resulting from placement and vibration of the concrete. When the forms slip during construction, they can produce slightly offset blocks and uneven joints and surfaces. Sometimes form slippage is mistaken for misalignment of the concrete, which usually occurs well after construction.

Stains

Although discoloration and staining sometimes are associated with deterioration of concrete, most stains on concrete surfaces cause only an unpleasant appearance rather than damage. Stains may have natural causes, such as deposits from runoff water or deposits from corrosion of exterior steel. They may also result from construction or maintenance accidents (e.g., oil, grease, paint, creosote, or asphalt).

Impact Damage

Damage to a concrete surface sometimes results from mechanical impact. For example, the impact of a truck, boat, or crane, or rock thrown into chutes can mar or chip away a portion of the concrete surface. While such damage is localized, it can lead to other damage, such as freeze-thaw action, by permitting moisture to enter the concrete.

Concrete Deterioration: Cavitation

Concrete deterioration is any adverse change on the surface or in the body of the concrete that is caused by separation of components in the concrete.

In spillways and outlet works, cavitation and erosion often are causes of deterioration, and therefore will be discussed in detail.

Cavitation occurs when a critical combination of the flow velocity, the flow pressure, and the vapor pressure in the water is reached. An offset or irregularity on a flow surface exposed to high velocities produces turbulence. This turbulence creates negative pressures that cause water to vaporize and form bubbles, or cavities, in the water. Bubbles collapse when subjected to higher pressures downstream from the formation site.

Bubble collapse dynamics then create shock waves that can damage the flow surface. Popping and crackling noises (crepitation) accompany the collapse of the cavities. The impact of the shock waves can produce pressures up to 100,000 pounds per square inch (70 million kilograms per square meter). Repetition of these high-energy blows eventually forms the pits or holes known as cavitation damage.

Common sites for cavitation are downstream from gates and valves, and in steep spillway chutes, tunnels, or conduits. Cavitation may occur on the floor of a chute or tunnel, or on the walls or sides of a structure.

Cavitation damage resembles erosion damage, but cavitation is potentially a much more serious problem. Once the process begins, deterioration can occur quickly. A tiny offset or carbonate deposit may induce cavitation, leading to serious damage or failure of the concrete in a spillway or outlet works during heavy flows.

A pitted surface and/or rough, ragged holes with aggregate plucked out suggest cavitation damage. Damage begins upstream and progresses downstream in a "leapfrog" pattern: each cavitation site triggers the deterioration of a new site downstream.

If cavitation is detected, the event causing the damage should be determined along with the potential for further damage.

Cavitation effects can sometimes be mitigated by repairing the area with stronger material such as steel polymer concrete. Installing aeration slots in tunnels eliminates negative pressures by providing additional air to the affected areas.

Concrete Deterioration: Erosion

Erosion in concrete usually begins with wearing away of the matrix material around the aggregate, and appears as relatively uniform damage over a large surface. In a spillway, erosion is usually due to the movement of abrasive materials being carried by the flowing water. Spillway aprons and stilling basins (also known as hydraulic jump basins or simply jump basins) are especially susceptible. Erosion often occurs after initial cavitation damage, and serves to increase and extend the damage.

Points of abrupt change in the flow channel or corners subjected to abrasive action are likely to show pronounced effects. Examples are bends leading from drop inlets to tunnels, conduits, and chutes, and energy dissipators in stilling basins

Ballmilling is a specific form of concrete erosion. Repeated rotation of debris (usually rocks) by discharging water grinds the surface, usually in a circular pattern. Stilling/hydraulic jump basins are prone to ballmilling damage.

If the flows continue for long time periods and if abrasive material is carried at relatively high velocities, extensive erosion damage to concrete structures results. Erosion in a stilling/hydraulic jump basin floor can excavate enough material to make the structure unstable.

Leaking Joints

Joints may leak because of damage to waterstops or other joint problems.

<u>Inadequate or Damaged Waterstops</u>

Concrete channels and conduits often include waterstops, which are continuous strips of waterproof material, usually metal, PVC, or rubber. During concrete placement, waterstops are embedded in joints between sections to prevent moisture from penetrating the joints by providing a restricted route for seepage water.

If damaged waterstops no longer provide a continuous seal, excessive seepage through the joint could erode foundation material or promote freeze/thaw damage to the joints.

<u>Other Joint Problems</u>

Joints should be inspected while dry if possible. Conduits also can be inspected just after dewatering, since water shoots back through the leaking joints, and the worst leaks can be identified. (Some leakage after dewatering is normal.) Sometimes construction joint drawings and joint survey information exist, and provide useful references when joint problems are suspected. The following points apply to inspection of joints:

- Soil fines oozing through a joint are evidence of seepage.
- Joints in concrete sections are often sealed with joint sealant, or plastic or rubber compression seals. When the sealant or seal is missing or hardened, the joint is exposed to damage. Vegetation in joints indicates damaged or missing joint sealant.

If the joint is located in a conduit running through the dam, missing or defective joint sealant is cause for concern.

METAL PROBLEMS COMMON IN SPILLWAYS AND OUTLET WORKS

Corrosion (Rust, Galvanic Action)

Corrosion is progressive deterioration resulting from exposure to moisture, acid and other corrosive agents, or electrolysis, and usually is marked by scaling or flaking, pitting, and color changes. Loss of paint or other protective coatings can leave a metal surface subject to corrosion, especially if the surface is cycled between wet and dry. Unchecked corrosion eventually leads to failure of a metal structure.

An anode consists of a metal that will corrode when in the same electrode as a metal needing cathodic protection. Zinc and magnesium often are used as sacrificial anodes. Be sure to locate and examine all accessible anodes installed for cathodic protection of metal portions of a spillway or outlet works. An anode may need replacement if it is excessively corroded.

Fatigue

Fatigue is loss of metal strength from repetitive loading, such as being bent back and forth. Protrusions on metal components or components with moving parts are most likely to suffer fatigue. Distortions or cracked paint may indicate sites where a metal structure suffers from fatigue. The process continues until the affected area cracks and/or breaks.

Erosion

Flow surfaces and areas around rivets and splice plates may be scoured by abrasive debris.

Tearing And Rupture

Tearing and rupture may result from impact, such as a log slamming into a steel lining. On spillways, metal components are most likely to tear and rupture during storms or other occasions when flows are heavy. Tears and ruptures can cause a metal structure to fail completely, or expose the structure to corrosion, cavitation, fatigue, or other damage.

Cavitation

Cavitation of metal surfaces, such as metal conduits, can occur when high flow velocities exist on a flow surface with offsets and irregularities. The bubble collapse dynamics of cavitation cause pitting of the surface, which results in progressive deterioration to the point of failure. As in concrete, the site of initial cavitation damage triggers the formation of another site downstream, so the process develops in a leapfrog pattern. Areas just downstream of gates and valves are susceptible.

Cracking

Cracking is usually induced by vibrations.

Deformation

Stress may deform metal shapes. ("Egg-shaped" pipe is an example.)

SPILLWAY AND OUTLET WORKS OBSTRUCTIONS

An obstruction is an unauthorized or unplanned addition to a spillway or outlet works that reduces flow capacity.

Significance of Obstructions

An obstructed spillway or outlet works cannot perform its function properly. During a flood, if reduced flow capacity prevents the spillway from diverting enough water from the reservoir or the outlet works from lowering the reservoir, the dam may be overtopped, and put in danger of failure.

Causes of Obstructions

- Overgrown Vegetation. Grass is the ideal cover for an earth-lined spillway. Shrubs, tall weeds, and trees reduce flow capacity.

- Aquatic Vegetation. Submerged aquatic plants such as water hyacinths can obstruct a submerged entrance channel to an outlet works. Algae is a problem at outlets.

- Adjacent Slope Failure. Causes for slope failure include overly steep channel and bank slopes, drawdown of a reservoir in saturated bank material, and flow undercutting banks/slopes due to:

  - Unprotected soil
  - High flow velocities
  - Loose or deteriorated bottom and slope material
  - Failed protective surface

- Debris. Dead trees, slide material, and other debris can form obstructions. Sediment accumulation, vandalism, and beaver activity are also sources of debris. The entrance channel, trashracks, and gates of an outlet works are liable to be obstructed by debris.

- Snow/Ice Dams. In areas that experience heavy snowfalls, snow collects in spillway channels and depressions. When spring snowmelt makes spillway use necessary, snow dams may block the spillways. In areas that typically receive heavy snowfall, look for measures to clear spillways of snow in operational plans.

- Beaver Dams. Beaver dams can obstruct channels, submerged structures, riser pipes, and box inlets.

- Manmade Structures. Fences or boat docks sometimes are built on earth-lined spillways. Also, unauthorized flashboards sometimes are added to the spillway control section. Watch for earth or concrete dikes or sills added to the crest to raise reservoir storage capacity.

SMALL-SCALE MISALIGNMENT

One type of small-scale misalignment, called differential movement, is localized movement of one section of a lining, wall, ogee monolith, or other spillway component relative to adjacent sections. Causes of differential movement include:

- Loss of foundation or backfill
- Expansive clay shale foundation
- Poor drainage resulting in pressure behind the structure

Small-scale misalignment may also result from misplacement during construction.

Significance of Small-Scale Misalignment

Small-scale misalignment is a significant problem because:

- Offsets on flow surfaces can cause erosion and, in some cases, cavitation. Both can eventually cause the structure to fail.
- Gaps between joints allow water to penetrate and undermine foundation material, creating excessive uplift pressure, and/or allowing earth or rock material to escape.
- Compression across joint surfaces can result in concrete spalling, metal deformation, or ruptured waterstops.

LARGE-SCALE MISALIGNMENT

Large-scale misalignment is the dislocation of entire structures from their design locations.

Causes of Large-Scale Misalignment

One example of large-scale misalignment is a conduit that sags below its design horizontal centerline. Deformations or failures responsible for large-scale misalignment include:

- Overcompacted backfill, excessive earth pressure, or hydrostatic pressure pushing the structure out of position
- Loss of backfill or foundation materials
- Base spreading
- Shear failure in foundation
- Settlement of foundation
- Seismic activity causing foundation collapse

Large-scale misalignment may cause a structure to fail. Landmarks, boundaries, and sighting techniques can be used to check for this problem.

FOUNDATION AND BACKFILL PROBLEMS

Foundation and backfill problems are related to many other problem conditions in spillways, both as the cause and as the result of those conditions. For example, misalignment is often the result of foundation, backfill, and drainage problems. (Gaps in spillway channel joints caused by differential movement, for example, expose the foundation to erosion.)

Factors in Foundation and Backfill Problems

- Seepage. Seepage can move materials by piping, undermining the foundation or backfill. A saturated soil base can shift or collapse.
- Erosion. The foundation or backfill adjacent to spillway channels or in the terminal area often suffers erosion damage.
- Settlement. Settling can cause misalignment.
- Foundation faults. Foundation faults can cause misalignment.
- Expansive foundation. Structures built on an expansive clay or clay shale foundation are subject to heaving and misalignment across joints.

SEEPAGE

Seepage in earth dams is the slow percolation of water through the embankment and its foundation.

Significance of Seepage

Both the velocity and quantity of seepage must be controlled or seepage erosion can occur.

Weepholes and Drains

Spillways commonly have weepholes or other means of drainage to prevent excess water pressure from developing behind a structure. When no weepholes or drainage systems exist, or when drains are plugged, excess water will accumulate. This is a problem for the following reasons:

- A saturated foundation has lower bearing capacity.
- Uplift pressure from seepage water may cause damage to a spillway chute.
- Structures are designed for certain waterloads. If these hydrostatic pressures are exceeded because of defective drainage, then instability or distress can result.

Weepholes can become plugged by debris, infiltration of fines, iron incrustation, and carbonate deposits. An inspection might include probing weepholes to check for obstructions and recording depth measurements on the crack maps. Signs of poor drainage include:

- Ponding of water behind walls
- Dampness on concrete surface, especially at cracks and joints
- Moisture seeping through cracks or joints
- Tilted walls or heaved slabs

SCHEDULING INSPECTIONS

Several factors should be considered relative to the timing of a spillway or outlet works inspections. These factors include:

- Sufficient notice to dam owners and operators. Two to three months may be needed to make necessary arrangements (such as special equipment or approval for dewatering conduits, basins, or pools). For dewatering of outlet works components to occur, a means of closure such as stoplogs or a bulkhead (plus any equipment needed for placement) may be necessary. Furthermore, the outlet works conduit must be able to withstand the external pressures that exist under dewatered conditions. The owner of the dam may be asked to formally certify the adequacy of the works for dewatered inspection.

- Optimum access. The inspection should be scheduled when all or most of the major components of a spillway or outlet works system can be examined. Submerged structures should be drained, if possible, before an inspection. The owner or operator may be requested to notify the inspectors when the reservoir level is scheduled to be drawn down, or when pools or other components are to be drained for maintenance or other purposes, so inspections can be performed under dry conditions.

- Observing operation. It is desirable to observe a spillway in operation, because problems or potential problems may be detected that would not appear when the same spillway is dry. It may be desirable to schedule an outlet works inspection for a higher regulated reservoir level than has previously existed to observe conditions under greater load.

It is unlikely to both gain optimum access and observe unusual stresses from operation during a single inspection of a structure. These two goals are often incompatible, and inspection objectives may have to alternate from one inspection to the next. Visits under different conditions can provide a comprehensive view of a structure's safety. For example, a dry conduit may display no visible joint problems, but just after dewatering, water might be seen spurting from some leaky joints into the conduit.

SPECIAL INSPECTIONS

If significant problems are noted during an inspection, an experienced and qualified engineer may be required to make a special inspection. Special inspections are also recommended after floods, earthquakes, or other unusual events that may have resulted in significant damage to structures.

DATA SOURCES

The project records that relate to spillways and outlet works are previous report summaries, prior inspection checklists, Standing Operating Procedures (SOP) manual, design documents, and construction drawings. (Construction drawings may not be available.)

PREVIOUS PROBLEM AREAS

Previous inspection report summaries contain findings and recommendations concerning problems and deficiencies. Before an inspection is made, these documents (including photographs and sketches) should be reviewed to determine what problems or types of deficiencies have been noted previously for the particular spillway or outlet works:

- Do the reports show any worsening trends?
- Does a chronic condition need to be rechecked?
- Do repairs need to be checked for structural and material adequacy?
- What kind of action was taken on previous recommendations?

CURRENT PROBLEM AREAS

Employees working at a dam may be aware of problems that have arisen since the previous inspection. These people should be interviewed about current operating changes and new problems and ask about leaks or cracks, and seepage adjacent to spillways or outlet works.

KNOWN DEFICIENCIES OR POTENTIAL PROBLEMS

During document review, the following situations should be noted:

- Obsolete construction methods. Examples include:

  - Conduit interiors not coated or lined.
  - Pipe joints not adequately sealed.
  - No moisture control procedures for curing concrete.
  - Lack of controlled compaction along a conduit.
  - Copper waterstops, which weaken over time and lack flexibility.
  - Concrete mixes not designed to resist local soil and water chemistry.

- Obsolete component configuration, equipment, or other features. For example:

  - Older methods of shaping inlets for gates.
  - Poor hydraulic shape of spillways and water passages, with abrupt bends causing flow separation, uplift, and cavitation.
  - Obsolete types of spillway gates, including counterweighted gates, bear trap gates, and roller gates. These types of gates allow little or no control, and can be unreliable.
  - Needle beams on spillways, which are hard to control, cannot be replaced without dropping the reservoir below the sill level, and are subject to severe weathering.

- Materials nearing end of life expectancy. Corrugated metal pipe (CMP) usually lasts 25-30 years, for example, while cast iron pipe has been known to last well over 100 years.

- Construction problems or anomalies. Such conditions as a fault zone crossing a conduit or channel, or a soft zone in the foundation that was not removed or treated should be noted.

- Inadequate inspection during construction. Special attention should be given to items that, according to records, were not subject to inspection.

- Spillways excavated through erodible materials. Slope failure, missing foundation material, and undercutting in the terminal area may exist at the site as a result.

- Base spreading. Unless the dam is founded on rock, joint separation at conduit or channel joints from base spreading may have occurred.

- Geologic faults or shear zones. Possible distortion or damage to channels or conduits where fault lines are crossed may have occurred.

- Compressible foundation. Differential settlement, especially at and near the interface of components such as conduits or channels with gate structures, and at monolith joints may have occurred. A conduit on a compressible foundation may crack, separate at joints, or have a misaligned gate or valve housing.

- Large gates. Differential settlement (especially on compressible foundations) and/or cracking between the gate structure and the channel or conduit may have occurred.

- Evidence of prior wall/slab movement. Inadequate relief of water pressure behind walls or under slabs may be occurring, as well as settlement.

- Pressurized outlet works conduit passing through the dam. The pressurized section is difficult to inspect, but if possible the integrity of the section should be checked very carefully, especially for an embankment dam. Cracks in the concrete or an inadequate weld at a steel pipe joint can allow pressurized water to be injected into the embankment.

  High-velocity flow. Cavitation damage at discontinuities in the flow surfaces, boundaries, or areas where negative pressure could develop is a possibility.

- Bedload (rocks, gravel, sand) liable to be drawn into the outlet works intake.

- Expect abrasion of the concrete and metal components.

- Detrimental water quality. If records show that local water is harmful to concrete, conduit, or waterstops, anticipate deterioration.

- Results of balance/imbalance tests on gates that indicate abnormalities.

TOOLS AND EQUIPMENT

The following items are considered useful when inspecting spillways:

- A rope and/or ladder for areas that are difficult to access
- Watertight boots
- Binoculars to check for cracks or defects in inaccessible areas
- Probe to measure crack, sinkhole, and weephole depths
- Rock hammer or chipping hammer to check concrete and rock surfaces and for finding hollow-sounding concrete

Copies of the inspection plan and the design or as-built drawings
Flashlight for tunnels and conduits
Stakes and flagging tape to mark sinkholes or unstable slopes
Boat (and related safety equipment) to provide easier access or easier inspection of some features
Crampons for shoe traction on ice and sloped or wet concrete
Bonker (a hardwood dowel with a metal tip) used to listen for hollow areas below surface facing
Hard hats and gloves

These additional items are useful for inspecting outlet works:

! Air quality monitors. If air quality or ventilation is poor, a compressed air supply and breathing equipment may be needed.
! Ear protection to be worn when gates, valves, or other equipment are to be operated
! Fathometer for determining depth of water in an entrance channel
! Remotely operated vehicle (ROV) with camera
! Safety glasses for inspection around machinery or in some narrow shafts
! Skateboard or creeper for an inspector to be pulled through small conduits
! Two-way radios or other communication systems
! Ultrasonic thickness-measuring device to determine thickness of metal

INSPECTING SPILLWAY AND OUTLET WORKS COMPONENTS

Entrance Channels

If a spillway or an outlet works has an entrance channel, this component is located upstream of all other components in the structure. The entrance channel is an open channel that conveys water from the reservoir to the control section or intake structure, and may be submerged or non-submerged.

Non-submerged Entrance Channels

To function as designed, a non-submerged entrance channel should provide an obstruction-free, uniform distribution of flow to the control section or intake structure. Common sites for non-submerged entrance channels are on spillways located at abutments or through saddles and ridges, and in outlet works used for irrigation or similar purposes. An entrance channel for an outlet works may be exposed in a dry dam or in a reservoir with a low water level, and yet function as a submerged channel when the outlet works operates. A channel which is not submerged at time of inspection may be considered non-submerged for inspection purposes.

Types Of Non-Submerged Entrance Channels

Non-submerged entrance channels may be lined or unlined. Unlined channels may be armored with a variety of materials, and can be excavated in rock or soil. Where possible, a soil channel should at least be vegetated to minimize erosion.

Channel liners may be constructed of:

- Concrete
- Asphaltic concrete
- Soil cement, roller-compacted concrete (RCC), or shotcrete
- Riprap
- Gabions

Elements of a Non-Submerged Entrance Channel

A non-submerged entrance channel consists of the following elements:

- Channel floor
- Channel walls
- Floating trash boom (optional). A trash boom is required across most non-submerged entrance channels.

Typical Problems with Non-submerged Entrance Channels

Failure of the entrance channel may block flow to the spillway or outlet works entirely, greatly reduce the flow capacity, or cause flow irregularities that impinge upon or overtop channel walls. As a result, the reservoir may be raised above safe levels, and the dam may even be overtopped.

Non-submerged entrance channels may be affected by deterioration of materials. Slope and wall failure may result when surface materials deteriorate.
Deterioration of surface materials should be checked as in the following table:

Inspecting Non-submerged Entrance Channel Materials

Material	**Inspection Point**
Concrete	Check concrete linings for cracks, displacement, and erosion.Sight along the walls to make sure that they have not moved.

RCC, Soil Cement, and Shotcrete	Check for cracks and erosion.
Asphaltic Concrete	Check for cracks, erosion, and disintegration.
Earth	Note any severe erosion gullies.
Rock	Look for excessive deterioration of rock in natural rock channels. Check riprap for weathering, deterioration of stone, and slides in side walls.
Gabions (wire cages filled with rock)	Note signs of gabion settling or rock deterioration. Check baskets for rusted, broken, cut, or deformed wires.

Non-submerged entrance channels may be obstructed by:

- Vegetation
- Debris
- Sediment
- Fallen rocks
- Trees
- Snow/ice dams
- Manmade structures (e.g., boat docks, etc.)

An inspector should check the following for obstructions:

- The trash boom for excessive debris. The floating trash boom protects the width of the channel.
- The channel for debris.
- The maintenance guidelines for the dam site include preventing ice buildup in the control section and possible removal of accumulated snow.

The following should also be checked during an inspection:

- The side slopes or walls for slides, movement, cracks, or wet spots.

- The topography above the channel for signs of instability, such as sinkholes or slumps behind the spillway walls.

- Any indications of poor drainage, such as seepage and clogged weepholes or drains.

  - Poor Floor Condition or Stability. These points should be checked when inspecting the entrance channel floor:

    - If the channel has an earth lining:
      - The toe of the channel slope for wet areas.
      - Erosion, sinkholes, and lack of vegetation.
    - Foundations for signs of undermining by flow from springs.
    - Signs of poor drainage, such as seepage and clogged weepholes or drains.
    - Voids under a concrete floor, using a bonker or a hammer. (Another device that may be used is a "chain drag," which is a series of chains fastened to a bar.)
  - Concrete Deterioration From Wetting/Drying. Concrete deteriorates from wetting and drying as the water level rises and falls, and from damage caused by freeze/thaw cycles. The waterline of the entrance channel needs to be checked for cracking, scaling, and crumbling of the concrete surface.

  - Wave Erosion. Earth or riprap linings should be checked for beaching from wave erosion. The overly-steep channel slope above the beach may fail.

  - Damaged Trash Boom. Trash booms have two purposes: to catch debris and to provide a safety barrier for boaters and swimmers. A variety of designs and materials may be used to construct floating booms. Buoyancy is often gained by using wood in the structure. The following are potential problems which should be noted:

    - Loose or missing anchorage.
    - Waterlogged and submerged wooden members.
    - Broken, bent, and missing parts.

  - Insufficient Capacity. If there is evidence of overtopping and a flow restriction does not appear to be a contributing factor, a hydrologic study should be conducted to see whether the entrance channel can satisfy requirements.

Submerged Entrance Channels

The entrance channel for an outlet works directs flows to an intake structure. The submerged entrance channel is normally constructed by excavating a channel to the intake structure. The channel may be lined or unlined, depending on the erodibility of the natural ground, and is general submerged after the reservoir is filled.

Typical Problems With Submerged Entrance Channels

Submerged entrance channels are less accessible than non-submerged channels. Typical problems--like slope instability and obstructions--can be difficult to detect. One problem that can occur with entrance channels is instability of unlined sloped sides (showing up as slumps and slides). Slope instability is most likely to develop during drawdown or other stress, such as seismic activity, or as a result of excessive internal pore pressures from higher-than-usual reservoir levels. Sudden mudflows or turbid water from the outlet may be indicative of an underwater slide. If a slump or slide occurs, the slumped material may restrict or even block the flow of water to the intake. If slope instability is developing or has occurred, one or more of the following recommendations may need to be made:

- Stability control measures such as riprap or gabion placement may be required immediately. Any materials blocking the channel must be removed.
- An engineering study to determine causes of the instability may be required.
- A monitoring program to measure changes should be installed.

Obstructions that can restrict the flow of water through a submerged entrance channel include:

- Siltation
- Slides or slumps
- Submerged trash buildup
- Aquatic vegetation such as water hyacinths (in shallow water)
- Beaver dams (in shallow water)

Restricted flow may be indicated by a lowered water rate when outlet works control settings have not changed. A review of operational records should indicate such a problem. Lowered flow rate also might be reported by water users. If the restriction is too severe and the outlet works is relied upon for passing floods, then overtopping of the dam may result.

If an inspection reveals a flow restriction due to trash, sediment, animal activity, or vegetation, the following recommendations may need to be made:

- The obstructive material should be removed immediately.

- Maintenance procedures should call for more frequent inspection by operational personnel, and more frequent trash or sediment removal.

- The anticipated trash burden based on use of the reservoir may need re-evaluation; the installation or improvement of trashracks may be warranted. For example, if large debris is getting between bars of the trashrack, a trashrack with smaller openings is probably needed. On the other hand, if relatively harmless debris such as grass is clogging the structure, a trashrack with larger spaces may, be more appropriate.

- Soil conservation measures upstream of the dam may need evaluation if excessive silt or debris is accumulating.

Intake Structures

An intake structure is the entrance to an outlet works, or may constitute the control section of a closed spillway. Intake structures may consist of some or all of the following features or elements:

- Riser or drop inlet
- Shaped entrance
- Auxiliary intakes
- Entrance transition
- Guard gate or valve
- Regulating gate or valve
- Trashrack and/or fishscreen
- Bulkhead, or stoplog closure device
- Access tower, bridge, or platform
- Ice protection system

Types of Intake Structures

The design of the intake structure can signal possible problems. The following descriptions of different types of intake structures include some inspection advice. Additional inspection tips for intake structures are provided with the discussions of the individual components.

Intake Structures For Concrete Dams

The intake structure for an outlet works through a concrete dam may be just an opening on the face of the dam. Appurtenances associated with the intake, such as bulkheads, trashracks, fishscreens, and control mechanisms, may be integrated into a "trashrack structure."

Risers

A riser is a simple L-shaped metal or concrete pipe that allows the reservoir to rise to a predetermined level before water flows into the pipe. Risers may have an open inlet, or may have a trashrack covering the inlet. A riser may serve as the control section of an enclosed spillway.

Drop Inlets

A drop inlet is a large intake device constructed of reinforced concrete. (Some agencies refer to such a structure as a riser.) A drop inlet may serve as the control section of an enclosed spillway.

Submerged Intake Structures

Submerged intake structures are common where little trash or sediment is expected to accumulate, and where icing is a concern. The structure serves only as an entrance to the conduit. Submerged intake structures are generally located at or near the reservoir bottom, depending on the amount of sedimentation that is anticipated for a particular site.

If there is significant buildup of trash or sediment, a submerged intake structure can become obstructed, leading to reduced flows or even the loss of drawdown capacity under emergency conditions. Long probes or rakes may be used to determine whether silt has accumulated at the intake, or trash at the trashrack. If inspection is not possible under dewatered conditions, serious consideration should be given to an underwater inspection, especially if there are any other indications of possible blockage.

Obstruction of submerged intake structures is most likely when reservoir levels are low, and inlets near or above the water surface can be blocked by floating debris.

Tower Intake Structures

Towers are common when it is desirable or necessary to have any or all of the following functions at the intake structure:

- Regulation of reservoir releases.
- Provisions (such as an operating platform) for trash removal, maintenance and cleaning of fishscreens, or installation of stoplogs.
- Provisions for several openings at different reservoir elevations to allow for selective withdrawal of reservoir water to control water quality, characteristics (temperature, taste, odor, dissolved oxygen, minerals).

The inside of the tower may consist of a wet well or it may provide access to a control mechanism. Tower intake structures normally require an access bridge from the dam crest or reservoir rim.

Inclined Intake Structures

Inclined intake structures are usually placed on the upstream slope of the dam or along the reservoir bank upstream of the dam. Depending on particular requirements and site conditions, inclined intake structures may be completely submerged, or extend above the maximum water surface elevation to provide the capability for gate operation at all reservoir levels.

Inclined intakes that extend above the water surface usually provide the same functions as a tower structure. Inclined intakes are often selected when sedimentation and stability concerns at a particular site are significant.

Auxiliary Intakes

An auxiliary intake may be attached to the main intake structure. Typical functions include diversion during construction or maintenance, low-flow releases, and/or selective withdrawal. Auxiliary intakes are commonly located low in the reservoir and provide water to a small conduit. Appurtenances such as trashracks and control mechanisms that may be required for an auxiliary intake are similar to those required for a main intake structure.

<u>Inspecting Intake Structure Elements</u>

Problems Common To All Types Of Intake Structures

Listed below are some general problems associated with all types of intake structures. Specific issues related to individual intake structure elements are detailed in the paragraphs that follow.

- Deterioration of materials - Intake structures that extend above the water surface may be subjected to accelerated deterioration from wetting and drying as the reservoir level rises and falls, and to freeze/thaw damage. If an intake is constructed of coated metal, there may be rust holes, especially at the ground line. Crack maps should be used or prepared while inspecting a concrete intake structure. Indications of new or worsened conditions should be noted.

- Structural damage to an intake structure - Structural damage may be indicated by a flow of water that continues into a conduit even when the reservoir level is below the opening of the intake structure, or when the gate is closed.

- Misalignment of an intake structure - Misalignment may indicate movement of the abutments or other serious structural problems that threaten the integrity of the dam.

In the paragraphs that follow, descriptions of the elements of an intake structure are accompanied by specific points that should be checked during inspection and recommendations that should be made.

Access Bridge To Intake Structure

Materials in the access bridge should be checked for the following deficiencies:

- Rot, broken members, and insect damage on wooden bridges and railings.
- Bowed or bent beams.
- Exposed metal and corrosion of reinforcement steel on concrete bridges at joints and water runoff points.
- Peeling or missing paint.

- Breakdown of welds or mechanical connectors, couplings, and flanges on steel flashing over joints.
- Loose or insecurely anchored guardrails.
- The condition of previously repaired areas.

The bridge supports should be checked for the following:

- Stress or frost cracking on concrete bridge supports built into the entrance channel or the reservoir.
- Evidence of movement of the bearing supports at the abutments.
- Misalignment or damage at sliding joints.

Stoplogs

Stoplogs may be logs, barrels filled with flotation material, timbers, or steel beams placed on top of each other, with their ends held in guides on each side of a channel or conduit, to provide an inexpensive and easy way of closing the waterway. Before using stoplogs for dewatering, it must be determined if the structure is adequately designed given the present loading of the reservoir.

Bulkheads

A bulkhead is used for sealing off an intake structure to dewater the outlet works for inspection and maintenance. Bulkheads may also be required for emergency closures, and should therefore be operational at all times. Bulkheads for a submerged intake may require a barge and divers for placement. Some installations include a gantry crane for placing the.

Due to their size and weight, bulkheads are usually stored outside, somewhere in the vicinity of the dam. If bulkheads have not been maintained properly, they may be unusable or require significant repairs. Test operation of a bulkhead should be planned so that it can be accomplished at the time of the inspection, if possible.

<u>Assessing the Adequacy of a Bulkhead</u>

A qualified and experienced engineer should have assessed the bulkhead for structural adequacy. If the bulkhead fails any of the following checks it should not test-operated:

- The current reservoir level should be compared with the level anticipated by the designers. If the normal reservoir level has been increased since the original design, the bulkhead should have been strengthened (or conservatively designed in the first place) so that it could withstand the increased load.

- If any equipment (for example, a gantry crane) is to be used for bulkhead placement, the condition of the equipment must be assessed before attempting to install the bulkhead.

Inspecting the Bulkhead For Operational Deficiencies

The bulkhead and its supports should be tested for operational deficiencies as follows:

- Bulkhead guides above the water should be examined to determine that they are serviceable.

- When the bulkhead is placed in the conduit opening, if it binds or will not slide into place, it should not be forced. If the binding or obstruction occurs below water level, an underwater inspection is warranted.

- If flow continues after placement of the bulkhead, there may be a structural problem. The source of the continued flow must be determined.

Making Bulkhead Recommendations

If an intake structure is supposed to have a bulkhead and inspection shows that bulkhead to be unsafe or inoperable, the following recommendations may be made.

- The bulkhead and/or its guide slots should be repaired.
- Storage and/or maintenance procedures should be revised for better operability.
- Equipment for placing the bulkhead under emergency situations should be repaired (or provisions for such equipment should be made).
- The bulkhead should be redesigned, if necessary.

If a bulkhead cannot be used during the scheduled inspection, it may be necessary to reschedule part of the inspection for a time when divers and/or underwater video equipment will be available. The decision regarding an underwater inspection will depend, in large part, on the remaining observations the inspector is able to make without dewatering the facility as planned.

Trashracks

The next element of an intake structure to consider is the trashrack. A trashrack is a grate made of metal or reinforced concrete bars that is placed across an intake structure to prevent waterborne debris above a certain size from entering the waterway. Trashracks that are submerged are in a stable environment and are not especially prone to deterioration. However, occasional or periodic exposure to the air can accelerate corrosion.

Ice loads can damage trashracks or their supports, especially if the reservoir elevation changes substantially after ice has formed on the intake structure.

Debris can clog or damage trashracks. Damaged or missing sections of a trashrack can allow debris to pass through the outlet works, damaging equipment located downstream. If debris is causing loss of capacity, localized high velocity and vibration may cause deterioration elsewhere in the structure during heavy flows.

A decrease in the discharge capacity of the outlet works is one indication of possible trouble with trashracks. Trashracks are often submerged and cannot be examined in the dry. If it is not possible to check a trashrack by probing and there is some indication of trouble with the trashrack, consider the use of a diver.

The inspection of trashracks should include:

- Removing any debris from the trashrack. After debris is removed, check for damage to bars and struts.
- Checking trashrack panels for corrosion, broken welds, and broken, bent, or missing bars.
- Checking the condition of the concrete supporting the trashrack.
- If trash build up is a problem, recommending changes in maintenance procedures so that trash is removed more frequently.

Fishscreens

Fishscreens can be used independently or in combination with trashracks. The openings are generally quite small and therefore more susceptible to plugging than the openings on trashracks. Periodic cleaning ("brooming" and spraying) of fishscreens is important. The problems associated with fishscreens are essentially the same as trashrack problems.

Ice Prevention Systems

In climates where ice can form around an intake structure and impair reservoir drawdown or evacuation capabilities, ice prevention systems may be in place. An ice prevention system consists of equipment for releasing compressed air below the components that are at risk. Air bubbles rising to the surface prevent the formation of ice. Satisfactory operation of ice prevention systems should be checked.

Shaped Entrances

Entrances into or within intake structures are usually rounded or otherwise specially shaped to streamline the flow of water and minimize hydraulic losses. Even so, localized zones of negative pressure resulting from rapid change in direction or discontinuities can cause vibration and/or cavitation damage. Consequently, an inspector should:

- Look for damaged concrete and exposed reinforcing steel, and
- If any portion of the entrance is lined with steel, ensure that no portion of the steel

liner is loose or missing.

Entrance Transitions

Intake structures that house controls often have specially formed entrance transitions through the control areas. If this portion of the structure is subject to high-velocity flow, it may be steel-lined, possibly with a coating. The liner surface can be damaged by cavitation, corrosion, or vibration. If steel plates are loose or missing, cavitation damage to the concrete can occur, which in turn could expose the reinforcing steel.

An inspection of the intermediate water passage of an intake structure should include:

- Checking for surface deterioration immediately downstream of all discontinuities such as gate slots, liner plates, air vents, or side entrances to selective withdrawal or low-flow discharge systems.
- Trying to determine the remaining thickness of the metal.

The Spillway Control Section

The spillway control section receives the flow of water, either from the entrance channel or directly from the reservoir, and usually directs the flow into a discharge channel, conduit, or tunnel. In some spillways, the control section releases water directly to the energy dissipation section, return channel, or streambed. The control section determines when water will be released through a spillway, preventing outflows below fixed reservoir levels and regulating the volume of releases when the reservoir is above those levels.

Control is fixed by:

- Control section geometry
- Control section dimensions
- Crest elevation
- Crest shape

Types of Spillway Control Sections

There are three main types of spillway control sections:

- Unlined control sections
- Lined control sections
- Fuseplug control sections

Unlined Control Sections

Most unlined control sections are open channel, usually on a level or very flat gradient, excavated in earth or rock. Non-woody vegetation or RCC may be used to cover the earth or rock to improve its resistance to erosion. (Grass or soil cement often is used to cover earth spillways.)

Use of devices such as valves, gates, and removable barriers varies the parameters of the control.

In the case of unlined auxiliary spillways, the control section also provides a bulk length. This is a sufficient mass of material, usually in situ earth or rock, to provide a barrier against complete breaching of the spillway during rare, severe flooding.

Lined Control Sections

A control section consisting of a length of open channel may be lined to protect the channel walls from erosion. Lined control sections may feature devices such as weirs or orifices to regulate and direct the flow of water into the discharge channel, conduit, or tunnel.

A weir or overflow crest, usually shaped into a sill, can be constructed of concrete, RCC, riprap, gabions, wood, or metal. An orifice may be the upstream opening of a pipe or conduit, or may be a tunnel opening, and sometimes includes a specialized structure such as a drop inlet.

Fuseplug Control Sections

A fuseplug control section is a special type of spillway control that may be constructed either in a lined or unlined open channel. The fuseplug consists of an embankment of erodible material placed across a spillway, and is intended to fail in a controlled manner during rare, severe flooding. Fuseplugs often are constructed with lower elevations in the middle and with higher segments at the channel sides, so that the segments will fail in progressive stages.

<u>Typical Problems with Spillway Control Sections</u>

The control section is a particularly critical portion of a spillway. The spillway must begin releasing water as intended by design, whether the flow is triggered when reservoir water reaches a predetermined level, or through the operation of gates or the removal/failure of stoplogs or flashboards.

The most serious danger posed by the inability of the control section to operate properly is that the reservoir may rise and overtop the dam.

Problems typical to the spillway control section include:

- Deterioration of Surface Materials. The following points in the control section should be checked for deterioration:

- Surfaces in areas of concentrated and high velocity flows, such as near gates, for erosion.

- Areas near large gates for cracking in concrete, and tearing, rupture, and fatigue in metal.

- The edges of orifices and the upstream edges of weirs for damage from battering by ice or debris. A boat may be used to examine the upstream side of a weir immediately adjacent to the reservoir.

- Obstructions. Besides general types of obstructions already discussed in this module, the following obstructions to control sections should be checked:

    - Ice buildup at the crest, ice jams, and snow dams.
    - Wind-blown sediment clogging air vents downstream from gates. (Air vents may be present if a conduit is located downstream of the control section.)
    - Unauthorized equipment (such as flashboards) added to the control section.

High velocity flows over a concrete surface containing abnormalities can initiate cavitation damage. Check surfaces carefully for offsets, small holes, and calcium carbonate deposits. The bearing surfaces where gates rest and areas immediately downstream of gate slots, liner plates, and air vents should be examined with special care.

The flashboard material should be checked carefully. Flashboard stanchions or the flashboards themselves typically are designed or sized to fail when the pool level reaches some predetermined elevation. Any replacement or alteration of the stanchion or flashboard material may delay or eliminate the designed failure, resulting in overtopping of the dam due to decreased outflow capacity of the spillway.

A fuseplug may be in place for many years before its intended failure in response to severe flooding. A number of problems can affect a fuseplug over time. A fuseplug, should be checked for the following:

- That the fuseplug is free of woody vegetation and debris. Some vegetation, such as grass, may be required by the design.

- Erosion and loss of embankment material that might cause the fuseplug to fail prematurely. A hand level can be used to measure the freeboard for losses or increases, or recommend a survey, to make sure that fuseplug dimensions conform to the design reflected in previous inspection reports and construction drawings. A "pilot channel" (notch) may be created in a fuseplug to facilitate failure. Such channels usually are not shown in specifications or drawings, but are not deficiencies.

- Alterations such as paving or unauthorized structures.

Deficiencies in the operating bridge, piers, decks, or other access structures on the spillway could make gates and other controls unworkable in an emergency, and collapse of the supporting structure could obstruct the spillway.

Stoplogs, flashboards, and structures adjacent to and supporting gates and valves, should be checked for the following:

- Displacement of structural elements or concrete deterioration that may be jamming or misaligning gates. Equipment should be operated, if possible, to detect jamming, or gates not seated properly on the crest. During operation, deterioration of material on the underside of the gates should be checked.

- Rotting and other deterioration of timber stop logs.
- Excessive leakage.
- Bent flashboards, misalignment of gate stems, and other signs of strain from holding water, or from debris, ice, or overtightening.

The following points should be considered during inspection of the control section for backfill and foundation deficiencies:

- Foundations in the control section often must bear the stress of heavy equipment. Displacements may indicate settling, foundation shifts, or undermining. Concrete channel walls and floors should be checked for voids.

- It is critical that gaps in joints do not expose foundation or backfill material where the spillway extends through the embankment section, and that waterstops, sealants, and compressive joint fillers are intact and in good condition.

- Weepholes and foundation drains should be checked for clogging.

The Outlet Works Gate or Valve Housing

Some small dams have no provision for controlled release of the impounded water. However, the outlet works of most dams are designed with controls (regulating devices) consisting of one or more gates or valves. The structure that supports or encases each of these controlling mechanisms can be referred to as the gate or valve housing.

The condition of the gate or valve housing may be critical to maintaining a gate or valve in a workable fashion and providing a safe environment for operating it during emergencies. The structural integrity of the enclosure and the condition of the access are important considerations during a dam safety inspection.
Gate or valve housings may be located at various points along outlet works conduits. Location determines many inspection concerns.

- An upstream gate or valve is located at the upstream end of the conduit, and may be part of the intake structure. The upstream control housing can suffer many of the same effects of ice damage and weathering stress as the intake structure (from repeated wetting and drying, and freezing and thawing). If trashracks are inadequate, debris may get into the gate or valve and damage the mechanism or its housing--possibly jamming it open or shut.

- A midstream gate or valve is located somewhere along the length of the conduit (inside or beneath the dam). Access via a gallery, adit, tunnel, or shaft is normally required. The enclosure structure (sometimes referred to as the "gate chamber") should be inspected for structural stability, access conditions, dryness, and safe operating conditions such as adequate ladders and railings, lighting, and ventilation. Also important are provisions for communications during emergencies.

- A gate or valve at the downstream end of a conduit is subject to icing.

Typical Problems in the Outlet Works Gate or Valve Housing

Upstream Transition Problems

The waterway immediately upstream of the gate or valve housing is called the upstream transition. This area should be examined carefully, particularly for the following items:

- All discontinuities for:

  - Cracks or displacement at joints
  - Erosion or cavitation damage
  - Loose or missing steel liner plates, gate guides, or seal plates
  - Exposed reinforcing steel

- The structural integrity of the concrete (or other piping material used) for evidence of stress, such as cracks or deformed shapes.

- Debris that may obstruct gates.

Gate or Valve Housing Problems

The gate or valve housing and any encasement concrete around the gate or valve should be checked for:

- Damaged welds
- Cracks or discontinuities between the housing and the conduit
- Loose gate guides
- Misalignments or displacement
- Erosion or cavitation of the flow surface
- Ice damage (if surfaces are exposed)

Downstream Transition Problems

The area where the gate or valve meets the conduit or outlet structure downstream is called the downstream transition. At the downstream transition, the shape of the waterway changes from the shape of the gate (usually rectangular) or valve to the shape of the downstream waterway. A portion of the transition may be steel-lined if the velocity beneath the regulating gate or valve is great enough to cause erosion of concrete.

Where there is more than one upstream conduit and gate or valve, at the gate or valve housing the multiple water passages may converge into a single conduit. At the downstream end of piers that separate multiple control gates, extreme turbulence and negative pressure can be created. These pressures can damage the walls and ceiling of the transition area and create discontinuities where the transition liner meets the conduit.

- As with the upstream transition, discontinuities should be checked for:
  - Cracks or displacement at joints
  - Erosion or cavitation damage
  - Loose or missing steel liner plates, gate guides, or seal plates
  - Exposed reinforcing steel
- The liner should be checked to see that it is soundly bonded to the concrete casing. A hammer or sonic instruments can be used to determine whether there may be voids in the concrete behind the liner.
- Metal thickness-measuring devices can be used to check the thickness of the liner.

The Discharge Channel

The discharge channel, if present, conveys flow from the control section to the energy dissipation section, return channel, or natural stream. The discharge channel should accommodate the entire

range of flows from the control section to prevent the integrity of the dam structure from being jeopardized.

Like entrance channels, discharge channels can be lined or unlined. Channel linings may be constructed of:

- Concrete
- Asphaltic concrete
- Soil cement, RCC, and shotcrete
- Riprap
- Gabions

<u>Elements of the Discharge Channel</u>

Each type of discharge channel consists of different elements.

- An unlined channel contains:
    - Side slopes or walls
    - Floor
- A lined channel has side slopes or walls and a floor, each consisting of:
    - Foundation material
    - Lining

Concrete linings may also contain the following elements:

- Weepholes, pipes, or other means of drainage
- Joints between sections
- Joint sealants, compressible joint filler, and waterstops
- Reinforcing steel
- Baffles or other energy dissipators

Drainage or inspection galleries may be located within a concrete spillway with an open discharge channel. Some composite dams feature a concrete spillway gravity section with embankment wings. Galleries in such a dam are part of the spillway structure.

<u>Typical Problems with the Discharge Channel</u>

A discharge channel often is subject to high velocity flows, so that damage can develop rapidly.

If the discharge channel fails:

- The spillway may not safely pass sufficient water to keep the reservoir at safe levels.
- Flood water can erode foundations and areas adjacent to the failed structure, endangering the dam.

Problems typical to the discharge channel include:

- Deterioration of Surface Materials. Cavitation is a problem likely to affect the discharge channel. Many discharge channels are set at relatively steep angles, and are liable to be exposed to high velocity flows.

Offsets, joints, depressions, calcium carbonate deposits, and other irregularities on the flow surface of the discharge channel should be carefully recorded, and nearby areas should be inspected for evidence of cavitation damage.

- Obstructions. Discharge channels should be checked for:

  - Uncontrolled vegetation
  - Rocks or material from a slope failure
  - Debris caught on chute baffles

- Slope and Wall Failure. The same inspection procedures apply as when inspecting slopes and walls in the entrance channel.

- Poor Floor Condition or Stability. The same inspection procedures apply as when inspecting floors in the entrance channel.

- Defective Joints. Joints in discharge channel should be examined for:

  - Separation and exposure of foundation material
  - Damaged or missing waterstops
  - Hardened or missing sealants or compressive joint fillers
  - Infiltration and exfiltration of water
  - Soil loss out of opened joints
  - Offsets at joints
  - Spalling caused by offsets

- Backfill And Foundation Deficiencies. High velocity flows passing through the discharge channel can erode unlined channels, or, in lined channels, can displace channel floors or walls and then erode backfill and foundation material.

- Areas of embankment dams adjacent to discharge channels that pass high velocity flows should be examined for erosion by water overflowing the channel walls.

- Displacements may indicate settling, foundation shifts, or undermining.

- A check should be made for voids under concrete channel walls and floors, and gaps where lined channel walls meet backfill.

- A check should be made for clogged weepholes and drains, and for seepage and other signs of problems with the drainage system.

Conduits and Tunnels

Conduits and tunnels are enclosed waterways that convey reservoir water through or around a dam.

A conduit is a pipe or box structure constructed by joining sections of pipe or conduit. A conduit can be constructed in an excavated trench, inside a tunnel, on the ground surface, or on supports above the ground. All outlet works waterways are conduits.

A tunnel is excavated through in situ material, usually from the dam, and may be lined with cast-in-place concrete, precast segments, or occasionally a steel liner. Some rock tunnels are unlined.

Conduits

Conduits can range from simple, bare CMP pipe placed through an embankment dam to sophisticated water conveyance systems that carry pressurized water. The components of a conduit are likewise varied. The following list is not comprehensive but gives an idea of some of the components and materials that make up the conduit of a dam.

- Pipe material: asbestos cement, cast iron, cast-in-place or precast reinforced concrete, corrugated metal, ductile iron, polyethylene, polyvinyl chloride, steel, vitrified clay, or wood stave.

- Lining for pressurized pipe: asphaltic concrete, coal-tar enamel, mortar, plastic, or rubber.

- Control or contraction joints sealed with waterstops, seals, or gaskets.

- Cutoff or seepage collars that encircle the conduit to lengthen the seepage path.

- Joint supports and collars used to prevent settlement and opening of the joints.

- Filtered drainage blanket: graded granular material that aids in drawing seepage away from the conduit, usually placed around the downstream part of the conduit.

- Bedding for the conduit: natural rock, concrete, or compacted foundation material that provides structural support.

- Outlet support for the conduit (discussed in the final section of this unit).

Implications of Outlet Works Gate or Valve Location

The placement of a gate or valve at the midpoint or downstream end of the outlet works influences the types of conduit problems that are typically encountered, and the urgency of remedial action.

- Midstream Gate or Valve. With a midstream gate or valve, the upstream section of conduit is under reservoir head and is subject to significant amounts of stress.

- Downstream Gate or Valve. If the control gate or valve is at the downstream end of the waterway, there is a section of pressurized conduit upstream of the device. All conduit upstream of a gate or valve is under pressure of the existing reservoir head at the time of the inspection.

External Inspection Procedures for Conduits

Evidence of potential conduit problems may be found by inspecting external features of the conduit (if it is exposed) or the embankment:

- If the material is reaching its life expectancy, it may be possible to dig down to expose all sides of the conduit at a point where the surrounding soil is still damp. The outside of the conduit should be examined for signs of deterioration. The condition of the outside of the conduit could be significantly different from the interior. In some cases, the soil protects the exterior from oxygen-induced corrosion. On the other hand, local site conditions may have accelerated the deterioration of the exterior. Consider the outside of the conduit to be just one indicator.

- Infiltration of soil into the conduit may cause:

  - A depression of the embankment along the centerline of the conduit.
  - Sinkholes and piping cavities that exit the surface. Holes taken over by animals may not be easily recognized as sinkholes or piping cavities.
  - Holes that appear to be in a line. These may be an indication that piping or settlement is occurring.
  - Fines in the discharged water.

- Seepage or indications that seepage is sometimes present. (This is best done while the conduit is full.) Indications of seepage are:

  - Wet spots
  - Increased vegetation, or the presence of plants that thrive in wet ground

- If water continues to flow when all intakes are closed, and the intakes are not leaking, water is entering the conduit from the embankment. The entry point should be located and a check made for fines entering the conduit along with the water.

- A check should be made for piping-related erosion around the conduit near the downstream end, and for voids or erosion in the embankment slope above the conduit outfall that may indicate piping. A check should be made for seepage adjacent to the structure. The situation may be especially serious if the seepage is carrying sediment.

- With exposed conduits, the supports should be checked for settlement or movement of the joints.

- The concrete anchors of exposed steel conduits should be checked for cracking, weathering, and/or chemical deterioration.

Internal Inspection Procedures For Conduits

The following difficulties may be encountered when inspecting conduit interiors:

- Dewatering difficulties. The conduit must be dewatered. However, dewatering may be impractical or impossible for one or more of the following reasons:

  - Lack of a bulkhead or other closure device
  - The need to limit maximum reservoir drawdown
  - The need to maintain water flows
  - Structural inadequacy of the conduit to withstand hydrostatic pressures in a dewatered condition

To assess the probable condition of the conduit interior, it may be necessary to rely on results of the exterior inspection.

- Inaccessibility of the conduit interior - The conduit may be too small or too dangerous for internal inspection by a person. One possibility is to use remotely operated video equipment. If that is not feasible, the inspection must be based on:

- The condition of the exposed portion of the conduit or the embankment above it.
- The internal inspection of accessible portions of the conduit. (Some details can be observed from the downstream end of the conduit with the aid of a strong light and possibly a mirror.)

One indication of settlement-related problems that may be observed from the downstream end of a conduit is the ponding of water in certain reaches of pipe.

A deficiency commonly encountered in the internal inspection of conduits is cracking. An inspector should be aware of previously reported cracks and note any new cracks, using a crack map or similar reporting method. To get some indication of whether cracks are continuous through a concrete structure, a geologist's pick or other hammer can be used to tap the concrete, listening for changes of pitch that gives clues as to the condition of the concrete. More comprehensive studies of the concrete using dye tests and sonic methods may be necessary if there are indications that the crack extends any distance into the structure.

When inspecting the interior of a conduit, the following should be documented:

- Cavitation damage downstream from gates and valves, and at sharp bends, joints, or other discontinuities.

- Corrosion of metal conduit or liner.

- Cracking: Using crack maps, the position, length, and orientation (transverse, longitudinal, or diagonal) should be recorded. Also the depth of the crack should be estimated.

- Damaged coating or lining materials. (Cracking or buckling is a sign of structural stress. Missing chunks can cause cavitation.)

- Debris impact.

- Deformation of the conduit shape.

- Efflorescence or gel on the concrete. (Indicates possible chemical deterioration of the concrete.)

- Erosion, especially in areas of high-velocity flow.

- Joint separation, compression, or deterioration. rivets, or flanges. Mention any unsound welds,

- Leakage from the conduit, or seepage entering the conduit.

- Misalignment of sections of the conduit.

- Plugged drain holes.

- Voids behind the conduit near any observed cracks, misalignments, or other areas of possible seepage.

Problems with conduits occur most often at joints, and special attention should be given to them during an inspection. Open joints can permit erosion of envelope material or cause leakage of water into the embankment during pressure flow. Joints in conduits should be examined in dry conditions, if possible. Inspection just after a conduit is dewatered may reveal the locations of leaks, because water sometimes spurts through affected joints.

Typically, conduit joints pull apart under the highest part of a dam and are under compression at the ends of the waterway. When inspecting conduit joints, the following should be checked:

- Examine joints for leaks.
- Examine the joints between adjacent sections of conduit for leaks and for ruptured waterstops.
- Compression spalling of concrete.
- Misalignment of sections due to differential settlement.

Tunnels

A tunnel may be lined with various materials or excavated through rock and left unlined. Problems with lined tunnels are similar to problems with conduit, since the lining material forms a conduit within the tunnel.

When inspecting an unlined rock tunnel, an inspector should look for the following deficiencies:

- Fallen rock blocking or obstructing the tunnel.
- Deterioration of rock at seams.

The Energy Dissipation Section

The role of the energy dissipation section of a spillway or outlet works is to reduce and direct the energy and velocity of the flowing water. Energy reduction is especially necessary when flows enter an unlined channel, natural streambed, or river. Various energy dissipating structures can be used in combination.

The energy dissipation section of a spillway or outlet works should protect the toe of the structure and the embankment groin and toe from erosion and undermining, as well as protect the adjacent embankment from currents and eddies in tailwater during high discharges.

Energy Dissipation Structures

The following energy dissipation structures will be discussed individually: baffles, steps, flip bucket, stilling/hydraulic jump basin, control valve, impact basin, stilling well, plunge pool, and apron.

Baffles

Baffles are series of upright obstructions that slow the water flow. They are usually constructed of concrete, though boulders embedded in the channel floor sometimes serve as baffles.

A baffled apron drop consists of an array of barriers set on the channel floor to dissipate the energy of the flow as it drops through the channel. This structure combines the water conveyance and energy dissipation functions by both conveying flows from the control section and dissipating energy.

Steps

The entire discharge channel may consist of a series of steps, or the energy dissipation section may be stepped to reduce water energy.

Flip Bucket

A flip bucket is an upturned structure at the end of a chute that changes and directs the flow by flipping water up into the air and toward a plunge pool. A flip bucket is often used when water depth does not permit a hydraulic jump to form. Flip buckets below the water surface or slotted flip buckets are sometimes referred to as roller buckets. A cutoff wall is used under a flip bucket or other terminal structure to prevent undercutting by erosion. Steel sheet piles, concrete, or (in rare cases) timbers are used to construct cutoff walls.

Stilling/Hydraulic Jump Basin

A stilling/hydraulic jump basin is a channel structure that dissipates the high kinetic energy of flows. A stilling/hydraulic jump basin often has one or more rows of barriers, such as chute blocks (positioned where the chute meets the basin floor), baffles (also known as baffle piers or floor blocks), and dentates (tooth-like sill configurations). The geometry of the structure usually forces a standing wave, characterized by eddies, air entrainment, flow deceleration, and an increase in flow depth. A stilling/hydraulic jump basin is often lined with concrete or riprap.

Control Valve

A control valve, typically a needle valve, may be placed at the end of an outlet works conduit to disperse the flow into a spray. The energy of the water then is directed into a pool for further control.

Impact Basin

An impact basin dissipates energy by impeding the flow with a stationary, hanging concrete baffle.

Stilling Well

A stilling well is a water-filled well. The outlet works enters the well at the bottom, and energy is dissipated by turbulence as flow rises in the well.

Plunge Pool

A plunge pool is a structure designed to prevent erosion in an area that receives a falling jet of water. Plunge pools usually are lined with riprap, have gradually sloping sides, and often are utilized at pipe and conduit outlets. The pool depth should be sufficient to avoid scouring of the bottom, and the length and width large enough to contain the flow without eroding adjacent areas.

Apron

A level section of concrete, riprap, or gabions, called an apron, is sometimes constructed downstream of the discharge to protect the channel or stream.

<u>Inspecting the Energy Dissipation Section</u>

These general guidelines apply to inspection of the energy dissipation section of a spillway or outlet works:

- First and foremost, the inspector must know how the structures are supposed to function.
- Close observations should be made of the structures when in use. Any unusual water currents, eddies, and swirls, especially return currents that would carry rock and debris into the structure from downstream should be noted.
- The existence of any sand boils should noted.
- If possible, the pool should be dewatered to inspect surfaces for damage.
- To inspect a large pool that cannot be dewatered, an inspection from a boat

should be conducted and soundings made with a plumb bob. Surveying equipment may be needed to determine the location of subsurface damage.

- Underwater inspections by divers are recommended if problems are suspected. As with any underwater inspection, a detailed inspection plan and a good communication system are important considerations for logging damaged areas.

Typical Problems with the Energy Dissipation Section

Damage can occur to all elements of an energy dissipation section because these structures reduce the velocity and dissipate the energy of a flow. If the energy dissipation structures fail to operate properly, the dam structure can be eroded at the downstream end, causing a loss of foundation support.

Problems typical to the energy dissipation section of a spillway or outlet works include the following:

- Deterioration of Materials. The actions described in the following table should be followed:

Inspecting Energy Dissipator Materials

Materials	**Inspection Points**
Concrete	The sides of chute blocks, baffles, and dentates are exposed to considerable turbulence, and any offsets or irregularities can trigger cavitation. Erosion damage from abrasion may occur on spillway aprons, the top surfaces and undersides of flip buckets, and the floors, walls, chute blocks, and dentates of stilling basins. If ballmilling is occurring, circular patterns in the floor or apron of stilling/hydraulic jump basins may be visible. Joints should be checked for spalls or settlement on one side. Joint sealant or compressive joint filler should be checked for cracking, and whether any is missing, moved, or deteriorated. A check should be made for corroded and damaged reinforcement resulting from erosion and cavitation damage. Concrete terminal structures are always reinforced. The submerged portions of plunge pools and stilling/hydraulic

jump basins should be examined while dewatered, if possible, or use divers. (An underwater camera or a remotely operated vehicle (ROV) might be used before divers.)

Riprap — The riprap should be checked for any displacement and for piping or voids beneath riprap.

Geotextiles — Riprap or gabion plunge pools and downstream channels should be checked for exposed geotextiles, which typically should not be exposed to direct flow or sunlight.

Energy dissipation sections should be checked for the following obstructions:

Debris clogging baffles

Plunge pools, stilling/hydraulic jump basins, and areas downstream of flip buckets filling with debris (often rocks thrown by people)

Return currents bringing downstream materials into the outlet structure

Heavy vegetative growth (such as thick grasses) in plunge pools

A boat can be used to perform a hydrographic survey of a large pool bottom to check for obstructions or damage.

Damaged or Missing Baffles. Baffles may be cracked, severely eroded, loose, or missing. Ice damage may have occurred if baffles are exposed during winter low flow.

! Misalignment of Walls or Baffles. The force of flows may deflect the position of terminal structures.

- ! Verticality and deviations in alignment should be checked.
- ! Instrumentation data can be checked for deflections.

Offsets may occur as a result of misalignment, and cavitation can develop downstream of such offsets.

- Malfunctioning Drains. A check should be made for clogged drains in the energy dissipation area and whether water flowing from drains is clear or contains sediment or fine material.

- Backfill And Foundation Deficiencies. The following points should be considered when inspecting the energy dissipation section for backfill and foundation deficiencies:

  - Examine plunge pools, hydraulic jump basins, and riprap-lined dissipators carefully for foundation and backfill problems. Look for settlement and cracks in backfill. Measure the size and distance of problem areas. Measure settlement depth and probe for voids and erosion channels.

- A check should be made for erosion of backfill behind the downstream portion of a stilling/hydraulic jump basin. Cutoff walls and reinforcing should not be visible.

- Settlement or improper elevation or length may change the jump location in stilling/hydraulic jump basins. A check should be made to see that the jumps occur within the structure at design locations. (If the spillway or outlet works is not operating, water stains on the wall will indicate where the jump is actually occurring.)

- A check should be made for misaligned walls, cracks in the basin, and cracked backfill for evidence that a jump basin is settling.

- A riprap plunge pool should be checked for undermining by loss of underlying soil or lack of filter action.

- If a plunge pool lining is sand or gravel, it should be checked for piping.

The Return Channel

Return channels convey spillway and outlet works discharges to the natural stream channel downstream of the dam structure. A properly operating return channel:

- Passes discharges safely without adversely affecting the design outflow rating of the spillway or outlet works structure.

- Does not impair the stilling capabilities of the energy dissipation component.

- Protects the integrity of the dam structure.

Types of Return Channels

Like entrance channels and discharge channels, return channels may be lined or unlined, and may be surfaced with a variety of materials.

Elements of the Return Channel

The return channel consists of the following elements:

- Channel floor or bottom, which should be uniform to avoid concentrating flows
- Channel slopes or sidewalls (also known as training dikes or training walls), which should contain flows to the channel proper and provide for stability against slope failure

Typical Problems with the Return Channel

The return channel acts to return spillway and outlet works discharges to the natural stream. If the return channel fails, excess discharge is likely to erode the lower portions of a spillway, the embankment groin and toe areas, or areas downstream of the dam. The return channel is subject to the same general problems with structure and material as other open channels, with the following additional concerns:

- Erosion. Discharges entering the return channel are generally at higher velocity than flows through the entrance channel. The return channel is very susceptible to erosion if not properly sized, aligned, and protected from excess velocity.

- Inadequate Length. The return channel should extend far enough downstream to ensure that flows will not damage the embankment groin and toe areas.

FUNCTION OF MECHANICAL EQUIPMENT

Listed below are the kinds of mechanical equipment that are commonly used in dams and their functions.

Gates and Valves

Gates and valves are devices used to control or stop the flow of water in a waterway. In general, gates consist of a leaf or member which is moved across the waterway from an external position. Valves, on the other hand, are fixed permanently within the waterway, and have a closure member that either is rotated or moved transversely or longitudinally in the waterway in order to control or stop the flow. There are two classifications of gates and valves, based on function.

- Control gates and valves are designed to regulate water flows, and therefore can be used fully open, fully closed, and at any setting in between.

- Maintenance/emergency gates and valves are used upstream of control devices, to act as standby or reserve closure equipment, or to stop the flow of water so that a gate, valve, or fluidway downstream can be serviced. Maintenance/emergency gates and valves are usually kept either fully open or closed.

Hoists and Operators

Hoists and operators are the mechanisms used to adjust the position of gates and valves. Hoists are employed exclusively with gates, to move them into and out of waterways, while the term "operator" is used to refer to positioning systems for both gates and valves.

Power Systems

Hoists and operators can be either manually, electrically, hydraulically, or pneumatically operated.

Auxiliary Power Systems

Auxiliary power systems are used in the event of failure of the primary power source (e.g., an electrical blackout). Some examples of these auxiliary systems are:

- Manually operated system
- Compressed-air system
- Emergency engine-driven electrical generator
- Portable auxiliary power unit

Miscellaneous Equipment

There are some other types of mechanical equipment that do not fall into the categories just discussed. These types of equipment are described below:

- Sump pumps are small pumps used to remove internal seepage that is collected in drains ("sumps") within the dam structure.

- Air bubbler systems are de-icing systems that are designed to protect structures or equipment from damage that can be caused by the force of expanding ice. They normally are used on the upstream side of intake structures, to circulate warmer water from the bottom of the reservoir to the top, in order to prevent icing around gate structures.

- Weather barrier doors are doors, often insulated with weathertight seals, that are used to prevent equipment from becoming inoperable when temperatures are below freezing.

- Air vents are steel pipes (or passages in formed concrete) that allow atmospheric air to pass to the downstream side of gates and valves. This air is needed to prevent the development of high negative or positive pressures that could cause damage to the gate/valve and downstream pipes.

- Reservoir level gauges are instruments that indicate the current level of water in a dam's reservoir.

- Trashracks are metal grates located at intakes to prevent floating or submerged debris from entering the intake.

PLANNING INSPECTIONS

If possible, planning for an inspection should begin at least two to three months before the scheduled date of the field visit, and often up to a year in advance. Such planning should consider:

- When reservoir water levels will be acceptable for testing mechanical equipment.
- What equipment will be accessible.
- The effect of seasonal influences on inspections.
- What assistance may be necessary (dam operating personnel, mechanics, divers, etc.) to assist with test operations and access to equipment.
- Coordination of the inspection with scheduled water releases, so that test operations can be conducted without violating water conservation restrictions or minimum stream flow requirements.

Its essential that an agenda be prepared before the day(s) scheduled for inspection and operational testing, and that a copy of the agenda is sent to the dam owner/operator.

Document Review

For any given dam to be inspected, there should be a wide variety of sources from which to learn about the inspection history of the mechanical equipment on that dam. These sources are described below and on the following page.

<u>As-Built Drawings</u>

It is important that the as-built drawings of the dam's mechanical equipment be reviewed to determine the type and location of the equipment to be inspected. Photographs and manufacturers' drawings of equipment at the dam may also prove helpful.

Design and Operating Documents

The written standing operating procedures (SOP) and designer's operating criteria (DOC) for the components of the dam should be reviewed, if they are available.

These documents describe how equipment is designed to operate, and enable the inspector to check during the inspection that the operating procedures described in the SOP are the same as those actually used by dam operating personnel.

Past Records

Trends in the behavior and deterioration of specific pieces of equipment can be ascertained by reading through previous inspection reports.

If any other forms of documentation, such as related correspondence files, manufacturers' specifications or acceptance reports, etc., are available they should also be reviewed.

GENERAL INSPECTION GUIDELINES

Tools and Equipment Needed

Some of the types of tools and equipment that may be needed during an inspection are listed below:

- Notebook and pencil
- Pocket tape measure
- Waders or other watertight boots
- Flashlight
- Camera with flash
- Electrical test equipment (e.g., megger, tachometer, ammeter, voltmeter, etc.)

Inspection Techniques

Periodic visual inspection and test operation of mechanical equipment is the most practical way to keep it operating smoothly and safely. The two most basic ways that ensure conducting a comprehensive inspection are by:

- Using a checklist that includes a logically ordered procedure for conducting the inspection, with specific problem areas to examine and operational tests to be conducted for each type of equipment inspected.

- Making note of anything that seems to be out of the ordinary, or that could present a safety, maintenance, or operational problem in the future, and including the problem area in an inspection report.

Personnel Safety

During an inspection the first concern should always be safety. Every dam has its own set of hazardous situations to be evaluated.

Proper clothing and equipment are essential to safety. Consideration should be given to the use of a hardhat, safety shoes, safety gloves, foul weather gear, goggles, safety belts, etc. A first aid kit should be carried. Whenever a boat is used in an inspection, those in the boat should be wearing life jackets. In addition, life jackets should be worn whenever there is a potential for falling in the water during an inspection (e.g., when working near a stilling basin).

Any dam equipment that has the potential for falling or moving should be blocked or otherwise secured before beginning the inspection.

"Red tag" and lockout procedures are used to prevent inadvertent use of equipment which, if activated, would endanger personnel. Before starting an inspection, the electrical and mechanical "red tag" and lockout procedures should be discussed with authorized project personnel, so that no gate, valve, or electrical circuit can be moved or energized when persons are in hazardous areas. If "red tagging" is not used or recognized at a facility, then padlocks and chains should be used to physically restrict use of equipment controls.
Adequate ventilation must be provided before a conduit, well, or other confined area is entered. An air monitor should be used to verify that the area is adequately ventilated.

Care must be exercised when working near equipment that has rotating parts, such as motors, pumps, gears, etc. Loose clothing should not be worn in these areas.

Only authorized and qualified dam tenders or operators should operate equipment.

Frequency of Inspection

The length of time allowed between periodic inspections of mechanical equipment depends, of course, on the type of mechanical equipment, the age of the mechanical equipment. Special inspections should be performed after unusual occurrences, such as floods, earthquakes, and sabotage.

INSPECTING THE MECHANICAL EQUIPMENT

The inspector's first step upon arriving at the dam site is to meet with the dam owner or operator to explain what mechanical equipment will be examined and test operated. This is accomplished most easily by going over the agenda that was sent to the owner/operator. Any problems that have been experienced since the last inspection should be discussed with the dam owner/operator.

VISUAL INSPECTION

In conducting the visual (non-operational) inspection, a check should be made of any areas that have been dewatered for the inspection. By checking those areas again after they have been rewatered, it is possible to obtain a more complete understanding of the condition of mechanical equipment found there. For example, if a gate had been dewatered for the purpose of inspection, the condition of the upstream side of the gate leaf could be obtained first, since it would not be under water. Then after the gate has been rewatered, a check could be made for leakage at the downstream side of the gate (which would now be under reservoir elevation, or head).

Checking Indicators

A check should be made of the availability of all indicators at the dam. Examples of some of the indicators to be checked are provided below:

- Reservoir level indicators
- Gate position indicators
- Hydraulic cylinder pressure indicators

Reviewing Operating Instructions

As the various pieces of mechanical equipment at a dam are inspected, The inspector should make sure that there are operating instructions for all equipment that requires instructions, and that the labeling of all controls on equipment (e.g., dials, indicators, switches, etc.) is consistent with the instructions.

Checking For Cavitation Damage And Galvanic Corrosion

Two of the most common defects associated with gates and valves are cavitation damage and galvanic corrosion.
Cavitation was discussed earlier as a potential problem with spillways and outlet works.

Galvanic corrosion is the result of electrical/chemical reactions between two dissimilar metals. Corrosion damage on a painted surface is indicated by areas of the surface in which the paint has been removed and the underlying metal has flakes and nodules of rust. The rust of ferric materials is usually brown and has a rough or flaky texture. Where pinholes have occurred in the paint surface the underlying metal will be pitted. Corrosion damage on an unpainted metallic surface will appear as a more uniform distribution of rust, except where erosion has removed the rust surface, resulting in differential removal of the metal.

It is very important that a check be made of the extent of cavitation damage and galvanic corrosion when inspecting a gate.

Inspecting the Gate Leaf

The gate leaf must be checked for seal damage, cracks, and damaged structural members.

Seal Damage. Seals used with gates can be either flexible (e.g., neoprene or rubber) or rigid (e.g., metal). Flexible seals may be damaged when the gate is handled during routine maintenance, when debris has caught between the seal and the gate frame, or when the surface that the seal mates with moves toward the gate leaf (causing the seal to be pinched or crushed). Flexible seals may also be damaged when the gate is exercised in the dry, as a result of the softer seal material rubbing against a harder material with debris particles caught between the two surfaces. Damage to rigid seals is usually due to foreign materials being caught between the mating surfaces.

The primary consequence of seal damage is leakage past the gate leaf. The loss of water may in some cases be acceptable, while in others it may not. If leakage occurs in the winter, ice can form downstream of the gate, over a period of time becoming thick enough to restrict flow when the gate is operated, or falling and damaging equipment located downstream from the gate. Ice forming around the seal will also increase friction and could result in the hoist being unable to operate the gate.

When leakage occurs past a seal on a gate leaf that is subjected to high hydraulic head, the velocity of the leaking water will be high. If there are any particles in the water, they will act as an abrasive on the downstream side of the gate leaf and the adjacent fluidway, resulting in progressive erosion of the leaf and fluidway.

Cracks. Cracks can occur in a gate leaf due to fatigue, overloading, or stress corrosion. If a crack reaches a critical length, that portion of the gate leaf will fail, resulting in loss of the whole leaf or just a section of the leaf. In either case, the leaf will not function as intended.

Damaged Structural Members. Structural members are often damaged by overloading the leaf. This can occur if a piece of debris becomes stuck under the gate leaf when the gate is being closed. The gate operator will exert its full pressure, since there is no signal from the limit switch to stop the operator, and the stress will be absorbed by the structural members in the leaf.

Damage can also occur when debris strikes the structural members. The result of damage to the structural members is a reduction in
the structural integrity of the gate leaf, possibly leading to failure of the leaf.

Inspecting the Gate Frame

Damage to the gate frame can cause the gate to leak and/or make the gate operate poorly or not at all. There are several defects that can affect the performance of a gate frame.

Bent Gate Guides And Seat. Damage to a gate frame is often incurred when an attempt is made to close the gate while debris is lodged in the gate opening. This action can bend the gate guides and/or the seat.

Warp Or Misalignment. Differential settlement in the structure that houses the gate can also damage the gate frame. Such settlement will result in warp or misalignment of the seat and/or guides, which are attached to the structure.

When inspecting a gate frame, look for leakage, which is an indication that something is wrong (i.e., the seat or guides are bent or warped).

Inspecting the Lifting Assembly

The operation of a gate's lifting assembly can be impaired by corrosion and by a damaged stern or stem guides.

Corrosion. Corrosion damage at the hoisting connection can eventually break the attachment between the stem and gate. The stem and stem guides can also be damaged by corrosion, especially if the gate is infrequently operated and/or the assembly is improperly lubricated. When inspecting a lifting assembly, look for corrosion at the hoisting connection and on the stern and stem guides, and check the assembly for proper lubrication.

Bent Stem And Stem Guides. Debris, ice, or other large matter slamming into the hoisting assembly can bend the stem and/or break, deform, misalign, or dislodge the stem guides. Forcing the gate into operation when debris is wedged in the gate opening or when the gate is "frozen" in place can have the same destructive effect on the stem and stem guides. When inspecting a lifting assembly, look for improper alignment of the stem and for misaligned, damaged, or missing stem guides. A bent gate stem may be an indication of improper limit switch operation or setting.

Inspecting the Air Vent

If an air vent has been included for use with a gate, it must be checked for clogging and for inadequate sizing.

Clogging. An air vent that is clogged, by either debris or corrosion, cannot perform its design function.

Inadequate Sizing. If a vent is too small to allow sufficient air into the conduit that it services, it will not function as designed. A review of design criteria should be made prior to the inspection and the criteria checked against field conditions. Judgments concerning proper vent sizing should be made by a qualified engineer.

Air vents are provided to ensure adequate ventilation to the area downstream from a gate or valve. The consequences of a clogged vent or an inadequately sized vent, both of which would result in an insufficient amount of air being allowed into the conduit, are very serious.

In the case of an emergency gate or valve, if there is inadequate ventilation, the sudden closure of the gate (or valve) in an emergency will result in subatmospheric pressures occurring downstream from the gate (or valve). These subatmospheric pressures may cause collapse of the conduit if insufficient stiffening was provided.

In the case of a control or maintenance gate, ventilation is needed so that cavitation will not occur when the gate is in operation.

An air vent also allows release of air to the atmosphere when filling a conduit. If some of the air in the conduit is not allowed to escape, it will become compressed and create an air bubble iii the conduit, possibly causing separation of the water column. If separation occurs, damaging pressure waves may develop in the conduit the next time water releases are made.

Inspecting Valves

The valves that are likely to be encountered vary greatly in design and construction, so there are relatively few inspection tasks that apply to all valves. Deficiencies associated with most types of valves are discussed below.

Surface Damage. The surfaces of a valve are, of course, susceptible to galvanic corrosion and cavitation damage. Paint or other protective coatings are often applied to the exposed surfaces of a valve. Such coatings can be damaged by corrosion and cavitation, and also by debris striking the valve surface.

Damaged Seals And Seats. A valve's seals and seats are also subject to deterioration over time, and to damage by foreign objects. Damage to seals or seats can result in leakage past the valve, vibration, and cavitation damage.

Damaged Structural Members. The structural members of a valve are most often damaged by vibration produced when the valve is operated. If damaged structural members are not repaired, they will continue to deteriorate, ultimately resulting in failure of the valve.

Checking for Illegal or Improper Use of Gates and Valves

Gates and valves sometimes are installed illegally or improperly, to increase the storage of the reservoir or to take advantage of reservoir head. While visually these gates and valves may appear to be appropriate, they will decrease the capacity of the spillway, or pressurize a conduit not meant to be pressurized. Examples of illegally or improperly used equipment include:

- A structure placed in the spillway crest to increase reservoir storage capacity, which may impair the proper operation of the dam in a flood situation.
- A valve installed at the downstream end of a nonpressurized pipe, which will pressurize the pipe, cause it to leak, and lead to piping through the embankment.
- Flashboards placed on radial gates.

A pre-inspection document review will help to identify illegally or improperly used gates and valves at the site. The approved "as-built" drawings should be checked against all installed gates and valves.

Inspecting Auxiliary Power Systems

All of the backup power systems at a dam must be visually inspected and test operated periodically, to ensure that they will perform properly if needed in an emergency situation.

Inspecting Hoists And Operators

All hoists and operators, and their control systems should be examined.

Evaluating Security

Security of dams is a complex issue. A dam's security needs are directly related to the equipment or the consequences of illegal or unauthorized operation of the dam outlet equipment or the disablement of that equipment. The security provided must be commensurate with the consequences. For some dams the security system may only require locking in place the handwheels that operate gates or valves. Other dams may require a sophisticated security plan, the implementation of which involves extensive locking, alarms, fencing, and security personnel.

When checking the adequacy of a dam's security system, the consequences of any potential unauthorized operation or illegal acts affecting the safety of the dam should be considered. For example, a dam with spillway gates that could be made inoperable, causing the dam to overtop in a storm, may require a sophisticated security system. On the other hand, a dam which has ungated spillways for flood control, and gated outlets capable of releasing relatively small flows for irrigation, minimum streamflow, etc., would have little need for security. Unauthorized operation of equipment on this type of dam would mainly, affect the owner and would not have an impact on dam safety.

Most dams requiring sophisticated security systems will have a security plan. For these dams, the inspection should include a review of the plan, an evaluation of the adequacy of the plan, and a check to see that the plan is being fully implemented. If such a dam does not have a security plan, a recommendation should be made to develop and implement a plan.

For dams requiring minimal security, the inspection should include checking to see what security has been implemented, and determining its adequacy. Recommendations should be made for upgrading the security system, if needed. Handwheels should be locked in place, control houses locked, and access to critical areas restricted.

TEST OPERATION

A test operation of a gate or valve ideally consists of operating it through a complete "cycle," from fully closed to fully open to fully closed, under maximum reservoir head. The main concern should be that the gate or valve in question operates, and does so smoothly.

In certain circumstances, it may not be practical, or even possible, to open or close a gate or valve fully. In such cases, the test operation procedure will have to be adjusted accordingly. In addition, equipment may be encountered that cannot be observed in operation, such as gates or valves that are embedded in concrete. The dam's logbooks may be consulted to learn more about the past operating histories of such equipment. These logbooks will include information on problems previously encountered with the mechanical systems, and the dates of recent gate and valve openings.

The primary concern should be that the gate or valve in question operates properly. The following are indications of potential operating problems with gates and valves:

- Jerky or rough operation

- Leakage
- Vibration
- Abnormal noises
- Binding

All primary and auxiliary power systems should be examined and used during the test. The equipment being tested should be operated through one cycle using the primary power system, then one cycle using the auxiliary power system.

During the test operation, the pressures indicated by the pressure gauges on the power system and on the operators should be checked to see whether unusual resistance is encountered during the operating cycle. Such resistance would be an indication of potential equipment malfunction. The normal operating pressures should be defined in the operating instructions. An indication of potential problems can be determined by comparing the pressures recorded from previous test operations.

The operation of the limit switches should be checked. This is done by operating the equipment through a full cycle and allowing the limit switch to deactivate the power source.

Conditions For Testing

Whenever possible, testing should be conducted under the maximum anticipated head and flow for a given conduit or gated spillway. Emergency gates in particular must be designed to operate under "unbalanced conditions" (i.e., they must be capable of being closed under maximum flow and pressure differences on the gate), since malfunctioning of the primary gate will result in uncontrolled flow.

Some gates should be tested under "balanced conditions," meaning that pressure on both the upstream and downstream sides of the gate is equalized (e.g., equal water pressure against both sides).

An emergency test operation should never be performed without first ensuring that the gate or valve is adequately vented. An emergency test operation is opening or closing a gate in an unbalanced condition. An experienced and qualified engineer will have to verify that the venting is adequate.

Responding To Problems

If a gate or valve is not operating, or doesn't do so smoothly:

- The gate or valve position(s) at which problems exist should be noted.
- A check should be made for loose mounting bolts.
- A check should be made for trash and debris.

- The elevation of both the reservoir and the downstream pool should be noted, to help in the analysis of the problem by a qualified engineer.
- The seals and seats should be checked for binding and damage.
- A check should be made for misalignment of parts.
- The equipment's lubrication should be checked, if applicable.

If the cause of any problems is not apparent after checking these items, a specialist should be consulted.

INSPECTION OF SLIDE GATES

A typical slide gate, also known as a "sluice gate," consists of a leaf or disk that is opened or closed by sliding in seating guides, generally with metal to metal sealing contact. Slide gates are used at the upstream end of outlet conduits and in wet wells, and can be installed either vertically or at an incline.

Slide gates generally require a certain head of water in order to seal in their closed position, or use a system of wedges to ensure proper sealing. They move in seating guides on each side of the gate, and are raised and lowered using a gate stem and operator. The gate stem is supported at intervals by guides to prevent bowing and buckling of the stem. The operator for smaller gates is usually a handwheel. Power operators are required for larger gates.

Slide gates are used:

- As control gates, to regulate the downstream water flow.
- As maintenance/emergency gates, to allow maintenance and/or inspection of downstream regulating valves.

Design Limitations

The following design limitations must be considered in the installation and inspection of slide gates:

- The conduit must be vented just downstream of the gate if used to regulate flow, and to allow filling of the downstream conduit.
- The adjustable guides, wedges, and stops that are used to ensure accurate seating and thus prevent leakage require precise setting. With gate use these items become loose, which can result in excessive leakage.

Problem Area

Cavitation damage can develop just downstream of any offsets in the fluidway, usually low in the corners.

Visual Inspection

When the gate is below waterline, a check should be made for leakage on the downstream side.

When the gate is dewatered, or divers are being used in the inspection, the gate frame should be checked to ensure that it is firmly attached to the inlet structure, and that all fastening nuts are in place and tight.

Test Operation

To test the gate, it should be operated under balanced, no-flow conditions (if possible). The leaf should be moved smoothly and without binding.

After ensuring that the downstream side of the leaf is adequately vented, the gate should be operated through full travel with full flow while subjected to maximum head (if possible). Check to see that the leaf moves smoothly and without binding.

INSPECTION OF HIGH-PRESSURE GATES

The high-pressure gate is basically a slide gate that consists of a rectangular or square leaf encased either in a cast iron or welded steel body. The top of the body is connected to a bonnet with a bonnet cover, above which the operator is mounted.

High-pressure gates are used in tunnels, conduits, or pipes near the center of earthfill dams, or at the downstream end of conduits or pipes. Often, high-pressure gates are used in tandem.

The gate leaf moves in seating guides positioned on the sides of the leaf. A stem connected to the top of the leaf passes through the bonnet and is attached to the hydraulic operator. High-pressure gates are used:

- As maintenance/emergency gates in tunnels, conduits, or pipes.
- As regulating gates at the end of conduits or pipes.
- In tandem, with the upstream gate acting as the guard gate, and the downstream gate acting as the regulating gate.

Design Limitation

The pipe or conduit must be vented just downstream of the gate if the gate is being used to regulate flow and to allow filling of the downstream conduit.

Problem Area

Cavitation damage can develop just downstream of any offsets in the fluidway, usually low in the corners.

Visual Inspection

The visual inspection of a high-pressure gate should include the following checkpoints:

- On the gate body and bonnet. A check for heavily corroded areas or areas damaged by cavitation, particularly on the sidewalls just downstream from the guide slots, and on the floor just downstream from the sill.
  Also, ensure that there are no damaged seats, loose or missing seat bolts, or clogged ventilation holes.
- Bonnet cover. A check for cracks in the cover or leaky gaskets at the flange where it joins the bonnet. Also a check for leakage at the piston stem packings (i.e., oil leaking from the upper packings, and water from the lower packings).
- Leaf. A check for heavily corroded areas or areas damaged by cavitation along the leaf bottom, cracked or broken ribs, loose stem connections, and damaged or badly worn seating surfaces.

Test Operation

To test the gate, it should be operated under balanced, no-flow conditions (if possible). The leaf should move smoothly without binding.

After ensuring that the downstream side of the leaf is adequately vented, the gate should be operated through full travel with full flow while subjected to maximum head (if possible). The leaf should move smoothly and without binding.