An Owners Guidance Manual
For the Inspection and Maintenance of Dams in New York State

June 1987
As a safety guide for dam owners, this manual includes important steps that dam owners can take on a direct and indirect basis to reduce the consequences of dam failure. The beneficiaries of such programs include both the general public and the dam owners themselves.

Although dams and reservoirs are important components of the national infrastructure, existing dams are getting older and new dams are being built in hazardous areas. At the same time, development continues in potential inundation zones downstream from dams. More people are at risk from dam failure than ever before despite better engineering and construction methods, and continued loss of lives and property from dam failures must be expected.

Many different people and organizations now contribute to dam safety, and many are striving to improve the national record. In addition, significant contributions to dam safety can be made by the owners themselves. Therefore, the authors strongly urge continued reference to and use of this manual. If but one life is saved through the application of the guidelines discussed in this manual, the effort involved in its development will be fully justified.

This manual stresses the importance to the dam owner of the development and active pursuit of a dam safety program oriented to the specific dam structure and site. Also emphasized are those public policy measures which the dam owner may be able to influence indirectly. These include land use decisions, public dam safety awareness and community warning and evacuation planning. All are steps that can mitigate life and property loss.

Appendix E, an integral part of the manual, provides space for each state to incorporate references to or discussions of individual state laws and policies relating to dam safety. Of course, if any portion of this manual is in conflict with individual state policies or statutes, the latter apply. Each state is encouraged to include this information prior to dissemination of the manual.
ACKNOWLEDGEMENTS

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AN APPROACH TO DAM SAFETY

There is an urgent and continuing need for dam safety in the United States because of thousands of dams are now in place across the U.S. and many more are being built each year. These dams are essential elements of the national infrastructure, but the public risk in case of failure is great; large and growing numbers of lives and valuable properties are at stake. Although there are many who are concerned about dam safety, legal and moral responsibility essentially rests with the dam owner. Dam owners serve society by meeting important national needs and, of course, may also profit from dam operations. However, these reasons do not justify the utility and effectiveness of ownership if the owner cannot provide safety for people and property. The costs of dam safety are small in comparison to those which follow dam failure, particularly in our modern "litigious" society. Liability due to failure could easily offset years of profitability.

The dam owner can directly influence the safety of a dam. Owners can and should develop their own safety program which includes such important elements as inspecting, monitoring through instrumentation, maintaining the structure, emergency action planning and operating. Such a program is directly related to the dam structure and its immediate environment and depends on the owner's knowledge of the dam and how it works.

INTRODUCTION TO DAMS

Dams may be either man-made or exist because of natural phenomena, such as landslides or glacial deposition. The majority of dams are man-made structures normally constructed of earthfill or concrete. It is important that a dam owner be aware of the different types of dams, essential component parts of a dam, important physical conditions likely to influence the dam, and how the key components function.

HAZARDS, RISK, FAILURES

Present national loss statistics from dam failure fully justify the need for dam owners to better understand the public risks involved with dam ownership, the kinds of hazards that promote these risks and the reasons why dams fail. Public risk is high because people have been allowed to settle below dams in potential inundation zones and because new dams are being built in less than ideal sites.

Other elements of risk include natural phenomena such as floods, earthquakes and landslides. These hazards threaten dam structures and their surroundings. Floods that exceed the capacity of a dam's spillway and then erode the dam or abutments are particularly hazardous, as is seismic activity that may cause cracking or seepage. Similarly, debris from landslides may block a dam's spillway and cause an overflow wave that erodes the abutments and ultimately weakens the structure.

The International Commission of Large Dams (ICOLD) has determined that the three major categories of dam failure are overtopping by flood, foundation defects and piping. For earthen dams, the major reasons for failure were piping or seepage. For concrete dams, the major reasons for failure were associated with foundations. Overtopping was a significant cause of dam failure primarily in cases where there was an inadequate spillway.

DEVELOPING A DAM SAFETY PROGRAM

Recognition of the causes and possible impacts of dam failure points out the need for a program to enhance dam safety. Such a program must be based on a safety evaluation to deter-
mine a dam’s structural and operational safety. The evaluation should identify problems and recommend either remedial repairs, operational restrictions and modifications, or further analyses and studies to determine solutions.

A safety program comprises several components that address the spectrum of possible actions to be taken over the short and long term. Development of a safety program involves a phased process beginning with collection and review of existing information, proceeding to detailed inspections and analyses, and culminating with formal documentation. Much of the preliminary work can be accomplished by the dam owner with the assistance of state and local public agencies. However, depending upon the number and seriousness of problems identified by the initial assessment, professional assistance by qualified engineers and contractors may be required.

Information presented in this manual provides direction on how to proceed with establishing an action to increase the safety of a dam. The discussion details technical and procedural components of the safety program, and necessary forms are provided.

The program of inspection for both the initial and continuing safety evaluations establishes the condition of the dam and provides the information necessary for determining specific actions to be taken regarding repairs, operations, and monitoring. The program is cyclical recognizing the need for continued vigilance. Emergency action can hopefully be avoided, but a well thought out plan of action in case of imminent or actual failure can greatly reduce damage and possible loss of life.

INSPECTION GUIDELINES

An effective inspection program is essential to identify problems and to provide for safe maintenance of a dam. The inspection program should involve three types of inspections: (1) periodic technical inspections, (2) periodic maintenance inspections, and (3) informal observations by project personnel as they operate the dam. Technical inspections involve specialists familiar with the design and construction of dams and include assessments of structure safety. Maintenance inspections are performed more frequently than technical inspections in order to detect, at an early stage, any detrimental developments in the dam; they involve assessment of operational capability as well as structural stability. The third type of inspection is actually a continuing effort by on-site project personnel (dam tenders, powerhouse operators, maintenance personnel) performed in the course of their normal duties.

INSTRUMENTATION AND MONITORING GUIDELINES

Instrumentation of a dam furnishes data to determine if the completed structure is functioning as intended and provides a continuing surveillance of the structure to warn of any unsafe developments.

Means and methods available to monitor physical phenomena that can lead to a dam failure include a wide spectrum of instruments and procedures ranging from very simple to very complex. Any program of dam safety instrumentation must involve proper design consistent with other project components, must be based on prevailing geotechnical conditions at the dam, and must include consideration of the hydrologic and hydraulic factors present both before and after the project is in operation. Instrumentation designed for monitoring potential deficiencies at existing dams must take into account the threat to life and property that the dam presents. Thus, the extent and nature of the instrumentation depends not only on the complexity of the dam and the size of the reservoir, but also on the potential for loss of life and property downstream.

An instrumentation program should involve instruments and evaluation methods that are as simple and straightforward as the project will allow. Moreover, the dam owner should make a definite commitment to a continuing monitoring program if the program is not continuing, the installation of instruments and procedures will be wasted. Obviously, the involvement of qualified personnel in the design, installation, monitoring, and evaluation of an instrumentation system is of prime importance to the success of the program.

Instrumentation and proper monitoring and evaluation are extremely valuable in determining the performance of a dam. Specific information that instrumentation can provide includes:

- Warning of a problem
- Definition of and analyzing a problem
- Proof that behavior is as expected
- Remedial action performance evaluation

MAINTENANCE GUIDELINES

A good maintenance program will protect a dam against deterioration and prolong its life. A poorly maintained dam will deteriorate and can fail. Nearly all the components of a dam and the materials used for dam construction are susceptible to damaging deterioration if not properly maintained. A good maintenance program provides not only protection for the owner, but for the general public as well. Furthermore, the cost of a proper maintenance program is small compared to the cost of major repairs or the loss of life and property and resultant litigation against the dam owner. A dam owner should develop a basic maintenance program based primarily on systematic and frequent inspections. Inspections, as noted in Chapter 5, should be done monthly and after major flood or earthquake events. During each inspection, a checklist of items calling for maintenance should be used.

EMERGENCY ACTION PLAN GUIDELINES

Although most dam owners have a high level of confidence in the structures they own and are certain their dams will not fail, history has shown that on occasion dams do fail and that often these failures cause loss of life, injuries and extensive property damage. A dam owner should prepare for this possibility by developing an emergency action plan which provides a systematic means to:

- Identify emergency conditions threatening a dam
- Expedite effective response actions to prevent failure
- Reduce loss of life and property damage should failure occur

A dam owner is responsible for preparing a plan covering these measures and listing actions that the owner and operating personnel should take. He should be familiar with the local government officials and agencies responsible for warning and evacuating the public.
It is important that dam owners make full use of others who are concerned with dam safety; emergency plans will be more effective if they integrate the actions of others who can expedite response. People and organizations with whom the dam owner should consult in preparing an emergency action plan include numerous local participants, state and federal agencies. An essential part of the emergency action plan is a list of agencies/persons to be notified in the event of a potential failure. Possible inclusions for this list should be obtained from and coordinated with local law enforcement agencies and local disaster emergency services. These are key people or agencies who can activate public warning and evacuation procedures or who might be able to assist the dam owner in delaying or preventing failure.

Certain key elements must be included in every notification plan. Information about potential inundation (flooding) areas and travel times for the breach (flood) wave is essential. Inundation maps are especially useful in local warning and evacuation planning. Detailed information about identification of inundation areas or the development of maps can be found by contacting the State Engineer’s Office or local planning offices.

**OPERATIONS PLAN GUIDELINES**

Establishing an operations procedure or plan calls for detailed:

- Dam and reservoir physical characteristics data
- Descriptions of dam components
- Operations instructions for operable mechanisms
- Inspection instructions
- Instrumentation and monitoring guidelines
- Maintenance operations guidelines
- Emergency operations guidelines
- Bibliographical information

A schedule should be established to include both day-to-day tasks and tasks performed less frequently throughout the year. The schedule formalizes inspection and maintenance procedures so that even an inexperienced person can determine when a task is to be done.

**MEASURES TO REDUCE THE CONSEQUENCES OF DAM FAILURE**

Liabilities which are determined following a dam failure strongly affect both organizations and individuals, governments and dam owners. Establishing liability is the legal means developed by society to recover damages due to a "wrong" (in this case, lack of dam safety) and represents another perspective on the dam safety problem. A thorough understanding of this legal process can help the dam owner decide the steps to be taken to reduce liability.

The dam owner can directly and indirectly influence the introduction and use of a variety of other measures that will serve to reduce the consequences of dam failure. For example, insurance against the costs which will accrue after a failure will save the dam owner money by spreading costs from a single dam owner to others. Some land use measures instituted by governments represent better means of mitigating future disasters. If people are restricted from living in inundation zones, then safety is radically improved. Instituting land use measures represents one of the most effective ways to save lives and property over the long term, but such steps are not always acceptable to governments. Thus, given that lives and property are at stake, increasing public awareness and governmental planning are vital measures that also must be considered as ways to reduce the consequences of dam failure.

Dam owners can obtain insurance directly and should do so. The other measures discussed here -- land use, public awareness and preparedness planning -- are essentially controlled by local governments. Therefore, dam owners would be wise to encourage as strongly as possible awareness and action in the public sector. Finally, they may also wish to hire consultants from the private sector when the information needed for prudent decisions exceeds their own expertise.
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CHAPTER 1
AN APPROACH TO DAM SAFETY

1.0 GENERAL
This manual is a safety guide for dam owners. There is a critical and continuing need for dam safety because of the thousands of dams now in place and the many new dams built each year. Although these dams are essential elements of the national infrastructure, the risks to the public posed by their possible failure are great; large and growing number of lives and valuable property are at stake. Although there are many who are concerned about dam safety, legal and moral responsibility essentially rests with the dam owner.

1.1 URGENCY FOR SAFETY
The critical need for dam safety is clear. World and national statistics on dam failures show an unacceptable record of losses in both lives and property. The International Commission on Large Dams (ICOLD) reports that more than 8000 people have died so far this century because of the failure of major dams. The record for U.S. losses from major dam failures in recent years, shown in Table 1.1 is also not encouraging. Actual national losses are much higher than indicated because the statistics shown cover neither small dam failures nor many combinations of dam failure and natural flooding events. A more specific examination of the national experience shows that over an 18-year period (1965-1983) thirty lesser failures, or serious incidents that almost led to failure, occurred in Colorado. The Johnstown, Pennsylvania disaster of 1889 is regarded as one of the nation's great catastrophes, and the potential for future similar catastrophes due to dam failure remains strong. Only a cooperative effort in dam safety involving owners and communities can lessen this potential.

1.2 DAM OWNERSHIP AND SAFETY
This manual can be applied to dams owned and operated by a wide range of organizations and people, including state and local governments, public and private agencies, and private citizens. Typical reasons for building dams include water storage for human consumption, agricultural production, power generation, flood control, reduction of soil erosion and recreation. Thus, dam owners serve society by meeting important national needs and may also personally profit from dam operations. However, these are not sufficient reasons for building or owning a dam if the owner cannot provide safety for people and property in potential inundation zones.

In both financial and moral terms, successful dam ownership and the maintenance of safety standards go hand in hand. Investment in dam safety should be accepted as an integral part of project costs and not viewed as an expendable item that can be eliminated if a budget becomes tight (Jansen, 1980). The costs of dam safety are small in comparison to those which follow dam failure, particularly in our modern "litigious" society. Liability due to a failure would probably negate years of potential profits. Many different concerns and possible rewards result from dam ownership, but in the end, success will be in large part measured by a continuing record of dam safety.

1.3 THE INCREASING COMPLEXITY OF THE DAM SAFETY PROBLEM
As national needs for water intensify and the value of water increases, more dams are being built. At the same time, many existing dams are reaching or passing their design life spans and, for various reasons, people continue to settle near dams. Further, as builders are forced to use poorer sites for dams, the job of protecting life and property becomes more difficult. Therefore, as dam
construction continues and the population grows, exposure of the public to dam failure hazards increases and the overall safety problem becomes more difficult.

Governments across the nation have shown increasing concern for this problem and have enacted laws, statutes and regulations that place an increased burden of responsibility on the dam owner. In most states, dam owners are held strictly liable for losses or damages resulting from dam failure. Concurrently, liability insurance costs have risen rapidly.

### 1.4 AN APPROACH TO DAM SAFETY

An owner should be aware of and use both direct and indirect means of achieving dam safety. He can, of course, monitor and work on factors directly in his control (example, structural integrity), and these direct efforts are detailed below. However, the owner may also influence governmental policy and work for positive change in statutes and laws that affect dam safety (example, zoning laws). Such indirect influence by an owner could result in a significant contribution to the reduction of the likelihood and consequences of dam failure and thus, to overall community safety.

Liability, insurance coverage, and the roles of the Federal and state governments should all be well understood by an owner. Additionally, an owner should have a thorough knowledge of a dam's physical and social environment, including knowledge of natural and technological hazards that threaten the dam, understanding of the developing human settlement patterns around the dam, and understanding of other events that can lead to structural failure. These indirect means of achieving dam safety are covered in more detail in Chapters 2, 3 and 10.

Dam owners can also influence the safety of dams in more direct ways. Owners can and should develop their own safety programs. These programs should include such important elements as inspection, monitoring through instrumentation, maintenance, emergency action planning, and proper operation. Such a program is directly related to a specific dam's structure and its immediate environment and depends on the owner's knowledge of the dam and how it works. Chapter 2 stresses the need for owner's knowledge about the dam, while Chapters 4 through 9 cover the development of a dam owner's safety program.

<table>
<thead>
<tr>
<th>Name &amp; Location of dam</th>
<th>Date of failure</th>
<th>Number of lives lost</th>
<th>Damages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mohican Park, Conn.</td>
<td>Mar 1963</td>
<td>6</td>
<td>$3 million</td>
</tr>
<tr>
<td>Little Deer Creek, Utah</td>
<td>Jun 1965</td>
<td>1</td>
<td>Summer cabins damaged</td>
</tr>
<tr>
<td>Baldwin Hills, Calif.</td>
<td>Dec 1963</td>
<td>5</td>
<td>41 houses destroyed, 986 houses damaged, 100 apartment buildings damaged</td>
</tr>
<tr>
<td>Swift, Mont.</td>
<td>Jun 1964</td>
<td>19</td>
<td>Unknown</td>
</tr>
<tr>
<td>Lower Two Medicine, Mont.</td>
<td>Jun 1968</td>
<td>9</td>
<td>6 houses destroyed, 20 houses damaged, 1 manufacturing plant damaged or destroyed</td>
</tr>
<tr>
<td>Lee Lake, Mass.</td>
<td>Mar 1967</td>
<td>2</td>
<td>546 houses destroyed, 538 houses damaged</td>
</tr>
<tr>
<td>Buffalo Creek, West Va.</td>
<td>Feb 1972</td>
<td>125</td>
<td>Unknown</td>
</tr>
<tr>
<td>Lake &quot;O&quot; Hills, Ark.</td>
<td>Apr 1972</td>
<td>1</td>
<td>Unable to assess damage because dam failure accompanied damage caused by natural flooding</td>
</tr>
<tr>
<td>Canyon Lake, S. Dak.</td>
<td>Jun 1972</td>
<td>33</td>
<td>Unknown</td>
</tr>
<tr>
<td>Bear Wallow, N.C.</td>
<td>Feb 1976</td>
<td>4</td>
<td>1 house destroyed, 711 houses destroyed, 3002 houses damaged, 246 business damaged or destroyed</td>
</tr>
<tr>
<td>Teton, Idaho</td>
<td>Jun 1976</td>
<td>11</td>
<td>6 houses destroyed, 19 houses damaged</td>
</tr>
<tr>
<td>Laurel Run, Pa.</td>
<td>Jul 1977</td>
<td>39</td>
<td>Unknown</td>
</tr>
<tr>
<td>Sandy Run and 5 others, Pa.</td>
<td>Jul 1977</td>
<td>5</td>
<td>9 houses, 18 house trailers and 2 college buildings destroyed; 6 houses, 5 college buildings damaged</td>
</tr>
<tr>
<td>Kelly Barnes, Ga.</td>
<td>Nov 1979</td>
<td>39</td>
<td>Unknown</td>
</tr>
<tr>
<td>North Creek, N.Y.</td>
<td>Nov 1979</td>
<td>0</td>
<td>Unknown</td>
</tr>
<tr>
<td>About 20 dams in Conn.</td>
<td>Jun 1982</td>
<td>0</td>
<td>Unknown</td>
</tr>
<tr>
<td>Lawn Lake, Colo.</td>
<td>Jul 1982</td>
<td>3</td>
<td>18 bridges destroyed, 117 businesses and 106 houses damaged, Campgrounds, fisheries, power plant damaged</td>
</tr>
<tr>
<td>DMAD, Utah</td>
<td>Jun 1983</td>
<td>1</td>
<td>Unknown</td>
</tr>
</tbody>
</table>

Source: Graham, 1983.
CHAPTER 2
INTRODUCTION TO DAMS

2.0 GENERAL
The purpose of a dam is to impound (store) water for any of several reasons, e.g., flood control, human water supply, irrigation, livestock water supply, energy generation, recreation, or pollution control. This manual primarily concentrates on earthen dams which constitute the majority of structures in place and under development.

2.1 THE WATERSHED SYSTEM
Water from rainfall or snowmelt naturally runs down hill into a stream valley and then into larger streams or other bodies of water. The "watershed system" refers to the drainage process through which rainfall or snowmelt is collected into a particular stream valley during natural runoff (directed by gravity). Dams constructed across such a valley then impound the runoff water and release it at a controlled rate. During periods of high runoff, water stored in the reservoir typically increases and overflow through a spillway may occur. During periods of low runoff, reservoir levels usually decrease. The dam owner can normally control the reservoir level to some degree by adjusting the quantity of water released by the dam. Downstream from the dam, the stream continues to exist, but because the quantity of water flowing is normally controlled, very high runoffs (floods) and very low runoffs (drought periods) are avoided.

2.2 TYPES OF DAMS
Dams may be either man-made or exist because of natural phenomena, such as landslides or glacial deposition. The majority of dams are man-made structures normally constructed of earthfill or concrete. Naturally occurring lakes may also be modified by adding a spillway to provide safe, efficient release of excess water from the resulting reservoir.

Dam owners should be aware of the different types of dams, essential components of a dam, how the components function, and important physical conditions likely to affect a dam. This chapter discusses several of these factors.

Man-made dams may be classified according to the type of construction materials used, the methods used in construction, the slope or cross-section of the dam, the way the dam resists the forces of the water pressure behind it, the means used for controlling seepage, and occasionally, according the purpose of the dam.

A. Component Parts - The component parts of a typical dam are illustrated in Figure 2.1. Nearly all dams possess the features shown or variations of these features. Definitions of the terms are given in the glossary of this manual, Appendix C. The various dam components are discussed in greater detail later in this manual.

B. Construction Materials - The materials used for construction of dams include earth, rock, tailings from mining or milling, concrete, masonry, steel, timber, miscellaneous materials (such as plastic or rubber), and any combination of these materials.

1. Embankment Dams - Embankment dams are the most common type of dam in use today. They have the general
Their side slopes typically have a grade of two to one (horizontal to vertical) or flatter. Their water retention capability is due to the low permeability of the entire mass (in the case of a homogeneous embankment) or of a zone of low-permeability material (in the case of a zoned embankment dam).

Materials used for embankment dams include natural soil or rock obtained from borrow areas or nearby quarries, or waste materials obtained from mining or milling operations. If the natural material has high permeability, then a zone of very low permeability material must be included in the dam to retain water.

An embankment dam is termed an "earthfill" or "rockfill" dam depending on whether it is comprised mostly of compacted earth or mostly compacted or dumped pervious rock.

2. Concrete Dams - Concrete dams may be categorized into gravity and arch dams according to the designs used to resist the stress due to reservoir water pressure. A concrete gravity dam (shown in Figure 2.3) is the most common form of concrete dam. In it, the mass weight of the concrete and friction resist the reservoir water pressure. A buttress dam is a specific type of gravity dam in which the large mass of concrete is reduced, and the forces are diverted to the dam foundation through vertical or sloping buttresses. Gravity dams are constructed of non-reinforced vertical blocks of concrete with flexible seals in the joints between the blocks.
Concrete arch dams are typically rather thin in cross-section (Figure 2.4). The reservoir water forces acting on an arch dam are carried laterally into the abutments. The shape of the arch may resemble a segment of a circle or an ellipse, and the arch may be curved in the vertical plane as well. Such dams are usually constructed of a series of thin vertical blocks that are keyed together; waterstops are provided between the blocks. Variations of arch dams include multi-arch dams in which more than one curved section is used and arch-gravity dams which combine some features of the two types of dams.

A recently developed method for constructing concrete gravity dams involves the use of a relatively weak concrete mix which is placed and compacted in a manner similar to that used for earthfill dams. This “roller compaction” construction technique has the advantage of both decreased cost and time. In addition, there are no joints where seepage could occur.

3. Other Types - Various construction techniques could be used in a single dam. For example, a dam could include an earth or rockfill embankment as well as a portion made of concrete. In such a case, the concrete section would normally contain the spillway or other outlet works.

Other construction materials such as timber or timber faced with steel sheeting have been used for dam construction in the past. In other cases, crib walls constructed of timber, steel, or steel mesh filled with soil or rock were used. In addition, many types of embankment and crib-wall dams employed a concrete or other impermeable facing to aid in water retention. Masonry dams (usually designed as gravity dams) were also popular about 100 years ago.
A recent and increasingly popular design for low-head dams (minimum height of water behind dam) involves the use of inflatable rubber or plastic materials anchored at the bottom by a concrete slab.

Some dams are constructed for special purposes such as to divert water or permit construction of other facilities in river valleys. These dams are termed diversion dams and cofferdams, respectively.

2.3 WATER RETENTION ABILITY

Because the purpose of a dam is to retain water effectively and safely, the water retention ability of a dam is of prime importance. Water may pass from the reservoir to the downstream side of a dam by:

- Seeping through the dam
- Seeping through the abutments
- Seeping under the dam
- Overtopping the dam
- Passing through the outlet works
- Passing over an emergency spillway

The first three modes are considered undesirable, particularly if the seepage is not limited in areal extent or volume. Overtopping of an embankment dam is also very undesirable because the embankment material may be eroded away. Additionally, only a small number of concrete dams have been designed to be overtopped. Water normally leaves a dam by passing through an outlet works; it should pass over an emergency spillway only during periods of very high reservoir levels and high water inflow.

A. Seepage Through a Dam - All embankment dams and most concrete dams have some seepage through the dam. The earth or other material used to construct embankment dams has some permeability, and water under pressure from the reservoir will eventually seep through. However, it is important to control the quantity of seepage by using low permeability materials in the construction of the dam and by channelling and restricting the flow so that erosion of embankment materials does not occur.

Seepage through a concrete dam is usually minimal and is almost always through joints between blocks or through cracks or deteriorated concrete which may have developed. Maintenance of these joints and cracks is therefore essential. The seepage water should be collected and channellized, so that the quantity of water can be measured and erosion can be minimized.

B. Seepage Around a Dam - Seepage under a dam, through the dam foundation material, or around the ends of a dam through the abutment materials may become a serious problem if the flow is large or if it has sufficient velocity to cause erosion. Seepage under a dam also creates high hydrostatic uplift (pore water) pressures which have the effect of an upward pressure diminishing the mass weight of the dam, making the weight of a gravity dam less effective and therefore, the dam less stable.

Seepage through abutments or foundations can dissolve the constituents of certain rocks such as limestone, dolomite, or gypsum so that any cracks or joints in the rock become progressively larger and in turn allow more seepage. Abutment or foundation seepage may also result in "piping" internal erosion in which the flow of water is fast enough to erode away small particles of soil. This erosion progresses from the water exit point backward to the water entrance point. When that point is reached, water may then flow unrestricted resulting in even greater erosion and probable dam failure.

Obviously, it is not desirable to allow large unrestricted seepage to occur. To minimize this possibility, dams are constructed with internal impermeable barriers and internal drainage facilities such as drain pipes, filter systems, or other drainage systems such as toe drains, blanket drains, or chimney drains.

Flow through a dam foundation may be diminished by grouting known or suspected highly permeable material, constructing a cutoff wall or trench below a dam, or constructing an upstream impermeable blanket. Figure 2.5 illustrates a cutoff trench and an upstream blanket.

In summary, the overall water retention ability of a dam depends on the permeability of the dam, the abutments, the foundation, and the efforts made to reduce that permeability or restrict the flow of water through those components.

2.4 RELEASE OF WATER

Intentional release of water, as stated earlier, is confined to water releases through outlet works or over emergency spillways. An outlet works commonly has a principal or mechanical spillway and a drawdown facility. Additionally, dams should be equipped with emergency spillways to manage extreme floods.

A. Principal or Mechanical Spillway - The principal or mechanical spillway maintains the normal water level in the reservoir. Its function is to pass expected flood flows past the dam in a safe and nonerosive manner. It may consist of a simple metal or concrete pipe through the dam or a system of gates that discharge water over the top into a concrete spillway. Either method uses the overflow principle. When the reservoir reaches a certain level, water flows into a stand pipe or riser pipe or over a gate. Intake structures for spillways must have systems that prevent clogging due to accumulations of trash or debris.

B. Drawdown Facility - All dams should have some type of drawdown facility which can:

- Quickly lower the water level if the dam is imminent
- Serve the operational purposes of the reservoir
- Lower the water level for dam repairs
- Purposely fluctuate the pool level to kill weeds and mosquitoes
The valve regulating the drawdown facility should be on the upstream end of the conduit to minimize the risk to the dam posed by a possible internal rupture of the pipe.

C. Emergency Spillway - As the name implies, an emergency spillway functions during emergency conditions to prevent overtopping of a dam. A typical emergency spillway is an excavated channel in earth or rock near one abutment of a dam. An emergency spillway should always discharge away from the toe of a dam, so that erosion of the toe will not occur. Furthermore, the spillway should be constructed in such a manner that the spillway itself will not seriously erode when it is in use. Obviously, erosional failure of the spillway could be as catastrophic as failure of the dam itself. An emergency spillway should be sized to convey the so-called "design flood" the rare, large magnitude flood used to establish design criteria. The spillways of many existing dams are now considered undersized because standards for the design flood have increased over the years.
CHAPTER 3
HAZARDS, RISKS, FAILURES

3.0 GENERAL

Dam failures are severe threats to life and property and are now being recorded and documented much more thoroughly than in the past. Recorded losses have been high. Life and property loss statistics fully justify the need for dam owners to better understand the risks to the public posed by dams, the kinds of hazards that promote these risks, and, generally, the reasons why dams fail. Improving a dam owner's understanding of realistic risks and possible reasons for failure is an essential first step in any overall effort to improve dam safety and preserve the benefits of dam ownership.

3.1 HAZARDS AS SOURCES OF RISK

Dam structure itself can be a source of risk due to possible construction flaws and weaknesses which develop because of aging. The site immediately surrounding the structure may also increase structural risk if the dam is not positioned or anchored properly or if excessive reservoir seepage erodes the foundation or abutments.

The physical hazards which can cause dam failure are translated into high risks when people or property are threatened, and where the high risks to which Americans are exposed are exacerbated by a number of important factors. For instance, in most states, people are allowed to settle below dams in potential inundation zones, thereby compounding risk.

Natural hazards such as floods, earthquakes and landslides are also important contributors to risk. These natural phenomena are considered "hazards" because development has placed people and property in their way, since most natural phenomena existed long before mankind established patterns of settlement. Failure to adjust to these events has been costly both to dam owners and the public in general.

Human behavior is another element of dam failure risk; simple mistakes, operational mismanagement, unnecessary oversights or destructive intent can interact with other hazards to compound the possibility of failure. Thus, a broad range of natural and human hazards exist that, taken separately or in combination, increase the probability of dam failure and injury to people and property.

The following discussion of some of the most significant hazards that lead to public risk illustrates the interrelationship of events that can lead to dam failure.

3.1.1 Natural hazards that threaten dams - The most important natural hazards threatening dams include:

- Flooding from high precipitation
- Flooding from dam failure
- Earthquakes
- Landslides

Flooding from high precipitation - Of the natural events that can impact dams, floods are the most significant. A floodplain map of the U.S. (Figure 3.1) gives some idea of the major flood-prone areas. Flash floods can happen anywhere - even on small drainages - but especially in the west. Floods are the most frequent and costly natural events that lead to disaster in the U.S. Therefore, flood potentials must be included in risk analyses for dam failure. Dams are sometimes constructed to withstand a probable maximum flood (PMF) assumed to occur on the upstream watershed; this assumed event becomes the basis for the design of safety factors built into the dam (e.g., enhanced structural elements or spillway capacity). However, dams are often built in areas where estimates of the PMF are based on rather short precipitation and runoff records. As a result, spillway capacity may be underestimated.
Flooding from dam failure - When a dam fails as a result of a flood, more people and property are generally placed in jeopardy than during natural floods. The Rapid City, South Dakota flood of 1970, which killed 242 people, caused a dam failure which added significantly to the loss of life. When a natural flood occurs near a dam, the probability of failure and loss of life almost always increases.

The sudden surge of water generated by a dam failure usually exceeds the maximum flood expected naturally; dam failure inundation zones and 100-year floodplains are seldom congruent. The upper portion of an inundation zone almost always exceeds the 100-year floodplain considerably; therefore, residences and businesses that would escape natural flooding can be at extreme risk from dam failure flooding. Hence, it is important to make residents of those structures cognizant of the full risk to which they are exposed so that they can respond accordingly.

When one dam fails, the sudden surge of water may well be powerful enough to destroy another downstream dam, compounding the disaster. The potential for such a snowball effect is great, but the problem may seem remote to a dam owner who has not studied the potential impacts of upstream dams on his own structure. Upstream dams may seem too far away to be a real threat, but inundation zones and surge crests can extend many miles downstream - especially if the reservoir behind the collapsed dam held a large quantity of water.

Earthquakes - Earthquakes are also significant threats to dam safety. Both earthen and concrete dams can be damaged by ground motions caused by seismic activity. Cracks or seepage can develop, leading to immediate or delayed failure. Dams such as those in California, located near relatively young, active faults are of particular concern; but dams (especially older concrete and earthen structures) located where relatively low-scale seismic events may occur are also at risk. Areas of the U.S. where significant seismic risks exist are indicated in Figure 3.2. However, recent detailed seismic analyses have indicated a much broader area of seismicity sufficient to damage dams; the seismic risk is essentially nationwide. Dam owners should be aware of the history of seismic activity in their locality and should develop their dam safety emergency procedures accordingly.

Landslides - Rock slides and landslides may impact dams directly by blocking a spillway or by eroding and weakening abutments. Indirectly, a large landslide into a reservoir behind a dam can cause an overflow wave which will exceed the capacity of the spillway and lead to failure. A large landslide can form a natural dam across a stream which can then be overtopped and fail. A landslide can form a natural dam across a stream which can then be overtopped and fail. In turn, failure of such a natural dam could then cause the overtopping of a downstream dam or by itself cause damage equivalent to the failure of a human-made dam. In addition, large increases in sediment caused by such events can materially reduce storage capacity in reservoirs and thus increase a downstream dam's vulnerability to flooding. Sedimentation can also damage low-level gates and water outlets; damaged gates and outlets can lead to failure.

SEISMIC RISK MAP OF THE UNITED STATES

ZONE 0 No damage.
ZONE 1 Minor damage; distant earthquakes may cause damage to structures with fundamental periods greater than 10 seconds, corresponds to intensities V and VI of the M.M.* Scale.
ZONE 2 Moderate damage; corresponds to intensity VII of the M.M.* Scale.
ZONE 3 Major damage; corresponds to intensity VIII and higher of the M.M.* Scale.
ZONE 4 Those areas within Zone 3 determined by the proximity to certain major fault systems.

*Modified Mercalli Intensity Scale of 1931

3.1.2 Hazards from human activity - Human activity must also be considered when analyzing the risks posed by dams. By convention, classification of potential dam failure risk is based on the severity of potential impact, not on the structural safety of the dam. Thus, dams that may be of very sound construction are labeled “high hazard” if failure could result in catastrophic loss of life – in other words, if people have settled in the potential inundation zone. The “high hazard” designation does not necessarily imply structural weakness or an unsafe dam. Lower classifications include “significant hazard” dams for which failure is estimated to result in large property loss, and “low hazard” dams for which failure is estimated to result in minimal property loss. The following is a recommended guide for classifying dam hazards (Table 3.1).

Risk may well increase through time because few governmental entities have found the means to limit settlement below dams. More high and significant hazard dams are continually being “created” as development occurs in potential inundation zones.

Many other complex aspects of settlement and development must be considered in assessing dam risks. Because of short-term revenue needs or other pressures, governments often permit development in hazardous areas despite long-term danger and the risk of high future disaster costs. Diversion of settlement away from potential inundation zones is a sure means of reducing risk, but is not always a policy suitable to the immediate needs of local government. Perhaps the ultimate irony for a dam owner is to have developed

<table>
<thead>
<tr>
<th>Category</th>
<th>Urban Development</th>
<th>Economic Loss</th>
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<tbody>
<tr>
<td>Low</td>
<td>No permanent structures for human habitation.</td>
<td>Minimal (Undeveloped to occasional structures or agriculture).</td>
</tr>
<tr>
<td>Significant</td>
<td>Urban development with more than a small number of habitable structures.</td>
<td>Appreciable (Notable agriculture, industry).</td>
</tr>
<tr>
<td>High</td>
<td>No urban development and more than a small number habitable structures.</td>
<td>Excessive (Extensive community, industry or agriculture).</td>
</tr>
</tbody>
</table>

(Source: U.S. Army corps of Engineers 1982b)
and implemented a safety program and then have settlement permitted in the potential inundation zone so that the owner's liability increases.

Two extremes of human purpose - the will to destroy through war or terrorism and the urge to develop and to construct - can both result in public risks. Dams have proven to be attractive wartime targets, and they may be tempting to terrorists. On the other hand, a terrorist's advantage from holding the public at risk may well be illusory; the deliberate destruction of a dam is not at all easy to bring about. Yet the possibility exists that such an act could take place, and it should not be discounted by the dam owner.

All sorts of other human behavior should be included in risk analyses; vandalism for example cannot be excluded and is, in fact, a problem faced by many dam owners. Vegetated surfaces of a dam embankment, mechanical equipment, manhole covers and rock riprap are particularly susceptible to damage by people. Every precaution should be taken to limit access to a dam by unauthorized persons and vehicles. Dirt bikes (motorcycles) and four-wheel drive vehicles, in particular, can severely degrade the vegetation on embankments. Worn areas lead to erosion and more serious problems.

Mechanical equipment and associated control mechanisms should be protected from purposeful or inadvertent tampering. Buildings housing mechanical equipment should be sturdy, have protected windows, heavy duty doors, and should be secured with deadbolt locks or padlocks. Detachable controls, such as handles and wheels, should be removed when not in use and stored inside the padlocked building. Other controls should be secured with locks and heavy chains where possible. Manhole covers are often removed and sometimes thrown into reservoirs or spillways by vandals.

Rock used as riprap around dams is sometimes thrown into the reservoirs, spillways, stilling basins, pipe spillway risers, and elsewhere. Riprap is often displaced by fishermen to form benches. The best way to prevent this abuse is to use rock too large and heavy to move easily or to flush grout the riprap. Otherwise, the rock must be regularly replenished and other damages repaired. Regular visual inspection can easily detect such human impacts.

Owners should be aware of their responsibility for the safety of people using their facility even though their entry may not be authorized. "No Trespassing" signs should be posted, and fences and warning signs should be erected around dangerous areas. As discussed in Chapter 10, liability insurance can be purchased to protect the owner in the event of accidents.

3.2 SITE-SPECIFIC STRUCTURAL RISK

Developing site-specific risk analyses involves consideration of a number of hazards. Such analyses are helpful in stimulating better awareness, planning and design. In some cases dam structure analyses are quantitatively based, and precise conclusions about engineering and design can be made. Probabilistic analyses can also be important and useful. Still, exact quantitative and probabilistic tools are not yet applicable in many situations and do not fully supplement or replace qualitative analyses - informed perception and judgment of the risks. Judgment and engineering experience should play an important role in reaching useful conclusions in any site-specific analysis of structural risk.

As mentioned in Chapter 2, structural risks tend to result from design and construction problems related to the dam materials, construction practice and hydrology. The complexity of the hazard is such that structural design and causes of dam failure are significant areas of research in engineering. Indeed better design criteria have been developed and safer dams are being built, but there is no basis for complacency. Dams continue to age, people continue to move into inundation zones and enough hazards exist that the net risk to the public will remain high for many years.

3.3 SOURCES OF DAM FAILURE

There are many complex reasons - both structural and non-structural - for dam failure. Many sources of failure can be traced to decisions made during the design and construction process and to inadequate maintenance or operational mismanagement. Failures have also resulted from the natural hazards already mentioned - large scale flooding and earthquake movement. However, from the perspective of the owner, the structure of a dam is the starting point for thorough understanding of the potentials for failure.

The International Commission of Large Dams (ICOLD) conducted a study of dam failures and accidents. Figures 3.3 through 3.5 summarize the data (which pertain only to dams more than 15 feet high and include only failures resulting in water releases downstream).

3.3.1 Three categories of structural failure - Three categories of structural failure alluded to in Chapter 2 are:

- Overtopping by flood
- Foundation defects
- Piping

Overtopping may develop from many sources, but often evolves from inadequate spillway design. Alternatively even an adequate spillway may become clogged with debris. In either situation, water pours over other parts of the dam, such as abutments or the dam toe and erosion and failure follow.

Concrete dams are more susceptible to foundation failure than overtopping whereas earthfill dams suffer from seepage and piping. However, when overtopping and foundation failures are lumped together, they represent 82 percent of the failures studied by the ICOLD.

Figure 3.3 shows the relative importance of these three main categories of failure. Overall, these three events have about the same rate of incidence. A more specific analysis of the potential sources of failure has to take into account types of dams. Similarly, the characteristics of the type of dam being monitored will point to problems requiring more careful attention by the owner when developing a safety program.
3.3.2 Failures by dam type - Figure 3.4 shows the relation between dams built and those that failed for various dam types from 1900 to 1969. Gravity dams appear the safest, followed by arch and fill dams. Butress dams have the poorest record but are also the ones used least.

**Embarkment or Earthfill Dams** - The major reason for failure of fill or embankment dams was piping or seepage (38 percent; Figure 3.3). Other hydrologic failures were significant, including overtopping and erosion from water flows. All earthen dams exhibit some seepage; however, as discussed earlier, this seepage can and must be controlled in velocity and amount. Seepage occurs through the structure and, if uncontrolled, can erode material from the downstream slope or foundation backward toward the upstream slope. This “piping” phenomenon can lead to a complete failure of the structure. Piping action can be recognized by an increased seepage flow rate, the discharge of muddy or discolored water below the dam, sinkholes on or near the embankment, and a whirlpool in the reservoir.

Earth dams are particularly susceptible to hydrologic failure since most sediments erode at relatively low water flow velocities. Hydrologic failures result from the uncontrolled flow of water over the dam, around the dam, adjacent to the dam, and the erosive action of water on the dam’s foundation. Once erosion has begun during overtopping, it is almost impossible to stop. In a very special case, a well-vegetated earth embankment may withstand limited overtopping if water flows over the top and down the face as an evenly distributed sheet and does not become concentrated in a single channel. Table 3.2 lists examples of earthen dam failures caused by some of these conditions.

### Figure 3.3 Cause of failure.
*Source: ICOLD (1973).*

### Figure 3.4 Age at failure.
*Source: ICOLD (1973).*

<table>
<thead>
<tr>
<th>Dam failures 1900-1975 (over 15 m height)</th>
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<tbody>
<tr>
<td><strong>CONCRETE</strong></td>
</tr>
<tr>
<td>OVERTOPPING</td>
</tr>
<tr>
<td>FOUNDATION</td>
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<tr>
<td>PIPING AND SEEPAGE</td>
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<tr>
<td>OTHERS</td>
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<tr>
<td><strong>FILL</strong></td>
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<td>OVERTOPPING</td>
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<td>FOUNDATION</td>
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<td>PIPING AND SEEPAGE</td>
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<td>OTHERS</td>
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<tr>
<td><strong>ALL TYPES</strong></td>
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<td>OVERTOPPING</td>
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<td>FOUNDATION</td>
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<tr>
<td>PIPING AND SEEPAGE</td>
</tr>
<tr>
<td>OTHERS</td>
</tr>
</tbody>
</table>

(excl. failures during construction and acts of war)
TABLE 3.2
EXAMPLE OF EARTHEN DAM FAILURES

SOUTHFORK, PENNSYLVANIA
The famous Johnstown disaster, caused by the failure of the South Fork Dam in 1889 in which 2,209 people were killed, is an example of the overtopping of an earthen dam. Heavy rainfall in the upper drainage basin of the dam filled the reservoir and caused overtopping. It was later calculated that if a spillway had been built according to specifications and if the original outlet pipe had been available for full capacity discharge, there would have been no overtopping.

TETON DAM, IDAHO
The Teton Dam failure in 1976 was attributed to (1) internal erosion (piping) of the core of the dam deep in the right foundation key trench, with the eroded soil particles finding exits through channels in and along the interface of the dam with the highly pervious abutment rock and tails to points at the right groin of the dam; (2) destruction of the exit avenues and their removal by the outrush of reservoir water; (3) the existence of openings through inadequately sealed rock joints which may have developed through cracks in the core zone in the key trench; (4) the development of piping through the main body of the dam that quickly led to complete failure; and (5) the design of the dam did not adequately take into account the foundation conditions and the characteristics of the soil used for filling the key trench.

BALDWIN HILLS AND ST FRANCES DAMS, CALIFORNIA
The Baldwin Hills Dam failed in 1963 following displacement of its foundation. Foundation problems were ultimately traced to seismic activity along nearby faults. The failure of the large St. Francis Dam (part of the water supply system for Los Angeles) in 1928 was also attributed to a variety of problems related to foundation pressures, seepage around the foundation and operation. (Jansen, 1980).

TABLE 3.3
EXAMPLES OF CONCRETE DAM FAILURES

AUSTIN, PENNSYLVANIA
An example of a foundation problem can be found in the failure of the Austin, Pennsylvania Dam in September, 1911. Evidently, the reservoir was filled before the concrete had set sufficiently. Eventual failure near the base occurred because of weakness in the foundation or in the bond between the foundation and the concrete.

WALNUT GROVE, ARIZONA
In 1890, the Walnut Grove Dam on the Hassayompa River failed due to overtopping, killing about 150 people. The failure was blamed on inadequate capacity of the spillway and poor construction and workmanship. A spillway 6' X 26' feet had been blasted out of rock on one abutment, but with a drainage area above the dam site of about 500 square miles, the spillway could not provide nearly enough discharge capacity.

(Jansen, 1980)

Concrete Dams - Failure of concrete dams is primarily associated with foundation problems. Overtopping is also a significant cause again primarily when spillways are built with inadequate capacity. Other causes include failure to let concrete set properly, and earthquakes. The examples summarized in Table 3.3 illustrate typical foundation problems leading to dam failure.

3.3.3 Age and its relation to failure- Figure 3.5 illustrates cause of failure as a function of a dam's age at the time of failure. Foundation failures occurred relatively early, while other causes generally took much longer to materialize. Thus, it is not surprising that a very large percentage of all dam failures occur during initial filling, since this is when design or construction flaws, or latent site defects, appear.

In summary, this outline of the hazards, risks, and failures associated with dams is provided to help owners have an overview of the problem with which they must deal. Each aspect of a safety program should be visualized by the dam owner in terms related to the most probable sources of failure for a particular dam.
Figure 3.5 Dam types (Western Europe and USA, 1900-1969).
4.0 OBJECTIVES OF A SAFETY PROGRAM

The significance of the dam failure problem points out the need for a dam safety program. Such a program should be based on an evaluation to determine a dam's structural and operational safety. The evaluation should identify problems and recommend either remedial repairs, operational restrictions and modifications, or further analyses and studies to determine solutions to the problems.

A safety program comprises several components addressing the spectrum of possible actions to be taken over the short and long term. These actions include:

- Assessing the condition of the dam and its components
- Conducting preliminary and detailed inspections
- Identifying repairs and continuing maintenance needs
- Establishing periodic and continuous monitoring capabilities over the long-term
- Establishing an emergency action plan to help minimize adverse impacts should the dam fail
- Establishing operations procedures which recognize dam failure hazards and risks
- Documenting the safety program so that the information established is available at times of need and can be readily updated

Development of a safety program involves a phased process beginning with collection and review of existing information, proceeding to detailed inspections and analyses, and culminating with formal documentation. Much of the preliminary work can be accomplished by the dam owner with the assistance of state and local public agencies. However, depending upon the number and seriousness of problems identified by the initial assessment, professional assistance by qualified engineers and contractors may be required.

4.1 GUIDELINES FOR ASSESSING EXISTING CONDITIONS

The guidelines for assessing existing conditions are a sequence of steps that will enable a dam owner to secure the information needed to determine the need for subsequent detailed investigations, repairs and maintenance. The steps include:

- Reviewing existing data
- Visiting the site
- Inspecting the dam
- Assessing significance of observed conditions
- Deciding what to do next

Reviewing Existing Data - The important first step is to collect and review available information on the dam - its design, construction, and operation. A first requirement is a good map of the site. Maps of the watershed and the downstream channel reaches are also valuable. The design of the dam and its appurtenant structures should be reviewed to assess its actual performance compared to that intended. Engineering records originating during construction should be reviewed to determine if structures were constructed as designed. Records of subsequent construction modifications should be collected, as well as operation records which document the performance of the dam and reservoir. Any previously prepared emergency action plan should be reviewed to determine if it is up to date and workable. All these records should be incorporated into a notebook or file; they are most important in establishing a safety program and its supporting documentation. Chapters 5 through Chapter 10 provide information to aid the development of such documentation. It may be, however, that no records exist. In this instance, a detailed examination of the structure is appropriate.

Visiting the Dam Site - The next step is to visit the site. Undoubtedly, the dam site is well known and has been visited numerous times, but in this visit, there are some particular things to look for. A fresh look at the
Figure 4.1 Procedural Guidelines for A Dam Safety Program

4.2 PROCEDURAL GUIDELINES - A SOURCEBOOK

This chapter provides an overview of how to establish a safety program. Subsequent chapters detail technical and procedural steps of the various safety program components. They include:

- Detailed Inspection Guidelines (Chapter 5)
- Monitoring and Instrumentation Guidelines (Chapter 6)
- Maintenance Guidelines (Chapter 7)
- Emergency Action Guidelines (Chapter 8)
- Operations Guidelines (Chapter 9)

These program components can be visualized as a sequence of initial and continuing activities to insure dam safety. They are illustrated in Figure 4.1.

Again, the program of inspection for both the initial and continuing safety evaluations establishes the condition of the dam and provides the base of information necessary for specific actions involving repair, operation, and monitoring. The flow chart illustrates the cyclical nature of the program and the need for continuing vigilance. Emergency action can hopefully be avoided, but a well thought out plan of action (Chapter 8) in case of imminent or actual failure can greatly reduce damage and loss of life.

4.3 DOCUMENTING THE SAFETY PROGRAM

It is important to document a safety program in order to make maximum, reliable use of information about the dam. The procedural guidelines that follow can serve as an outline or table of contents for a safety program report. The operations plan (Chapter 9) presents a detailed outline of the information that should be included in the documentation. The chapters which follow suggest forms for inspections, monitoring, etc. which can be used to record information. It is helpful to maintain all the material in a single notebook or file so that it can be updated and available when needed. Duplicate copies of much of the file should be stored at a different location from the original.
Table 5.1 lists features to be inspected at a dam and the problems or deficiencies to be looked for. The specific sections of this manual in which the various features are discussed are also indicated.

### Table 5.1: Inspection Guidelines Directory

<table>
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<tr>
<th>FEATURE</th>
<th>ALIGNMENT</th>
<th>ANIMAL BURROWS</th>
<th>CRACKS</th>
<th>DEBRIS</th>
<th>DETERIORATION</th>
<th>EROSION</th>
<th>HUMAN ACTIVITY</th>
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CHAPTER 5
INSPECTION GUIDELINES

5.0 INTRODUCTION
An effective inspection program is essential for identifying problems and providing safe maintenance of a dam. An inspection program should involve three types of inspections: (1) periodic technical inspections; (2) periodic maintenance inspections; and (3) informal observations by project personnel as they operate the dam. Technical inspections must be performed by specialists familiar with the design and construction of dams and should include assessments of structure safety. Maintenance inspections are performed more frequently than technical inspections in order to detect at an early stage any developments which may be detrimental to the dam. They involve assessing operational capability as well as structural stability. The third type of inspection is actually a continuing effort by on-site project personnel (dam tenderers, powerhouse operators, maintenance personnel) performed in the course of their normal duties. Education of new personnel is required to assure the continued effectiveness of these inspections.

Visual inspection performed on a regular basis is one of the most economical means a dam owner can use to assure the safety and long life of a dam and its immediate environment. Visual inspection is a straightforward procedure that can be used by any properly trained person to make a reasonably accurate assessment of a dam's condition. The inspection involves careful examination of the surface and all parts of the structure, including its adjacent environment. The equipment required is not expensive, and the inspection usually can be completed in less than one day.

5.1 INSPECTION GUIDELINES
Table 5.1 lists dam components and conditions which may be observed during an inspection. The table summarizes the detailed guidelines presented in subsequent sections of this chapter.

Section 5.3 Embankment dams
Section 5.4 Concrete dams
Section 5.5 Spillways
Section 5.6 Inlets, outlets and drains
Section 5.7 Other areas

At the end of the chapter, diagrams and tabular listings of the guidelines (Figures 5.3 through 5.6) are presented for the various dam components. The guideline tables provide a quick reference to be used in assessing observed conditions, their probable cause and possible consequences, and remedial actions. The guidelines also point out the HAZARDOUS problems where evaluation by an ENGINEER is required.

The dam owner, by applying the maximum prudent effort, can identify any changes in previously noted conditions that may indicate a safety problem. Quick corrective action to conditions requiring attention will promote the safety and extend the useful life of the dam while possibly preventing costly future repairs.
5.2 ORGANIZING FOR INSPECTION

All inspections should be organized and systematic, and inspectors should use equipment appropriate for the task, record observations accurately, and survey the structure and site comprehensively.

Equipment - Equipment useful for inspections is listed in Table 5.2.

Recording Inspection Observations - An accurate and detailed description of conditions observed during each inspection will enable meaningful comparison of conditions observed at different times. All measurements and observed details required to get an accurate picture of a dam's current condition and possible problems should be recorded. This information has three elements:

1) Location - The location of any questionable area or condition must be accurately described so that the area or condition can be evaluated for changes over time or reexamined by experts. Photographs can be helpful in this regard. The location along the dam, as well as above the toe or below the crest, should be established and recorded. Problems in the outlet or spillway should be similarly located.

2) Extent or Area - The length, width, and depth or height of any suspected problem area should be determined.

3) Descriptive Detail - A brief yet detailed description of an anomalous condition should be given. Some items to include are:
   - Quantity of drain outflows
   - Quantity of seepage from point and area sources
   - Color or quantity of sediment in water
   - Depth of deterioration in concrete
   - Length, displacement, and depth of cracks
   - Extent of moist, wet, or saturated areas
   - Adequacy of protective cover
   - Adequacy of surface drainage
   - Steepness or configuration of slopes
   - Apparent deterioration rate
   - Changes in conditions

Coverage - An inspection is conducted by walking along and over a dam as many times as is required to observe the entire structure. From any given location, a person can usually gain a detailed view for 10 to 30 feet in each direction, depending upon the smoothness of the surface or the type of material on the surface, (i.e., grass, concrete, riprap, brush). On the downstream slope a zigzag inspection path should be used to assure that any cracking is detected.

Sequence - A sequence of inspection insuring systematic coverage of an entire site is:
   - Upstream slope
   - Crest
   - Downstream slope
   - Seepage areas
   - Outlet
   - Spillway

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**TABLE 5.2**

Inspection Equipment and Its Use

<table>
<thead>
<tr>
<th>Equipment</th>
<th>Description</th>
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<tbody>
<tr>
<td><strong>Inspection Checklist</strong></td>
<td>Serves as a reminder of all important conditions to be examined.</td>
</tr>
<tr>
<td><strong>Notebook and Pencil</strong></td>
<td>Should be on hand so that observations can be written down at the time they are made, thus reducing mistakes and avoiding the need to return to the site to refresh the inspector's memory.</td>
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<tr>
<td><strong>Tape Recorder</strong></td>
<td>Can be effective in making a record of field observations.</td>
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<tr>
<td><strong>Camera</strong></td>
<td>Can be used to provide photographs of observed field conditions.</td>
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<tr>
<td><strong>Hard Hat</strong></td>
<td>Should be used when inspecting large outlets or working in construction areas.</td>
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<tr>
<td><strong>Pocket Tape</strong></td>
<td>Provides accurate dimensional measurements so that meaningful comparisons can be made of movements.</td>
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<td><strong>Flashlight</strong></td>
<td>May be needed to inspect the interior of an outlet in a small dam.</td>
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<tr>
<td><strong>Shovel</strong></td>
<td>Useful in clearing drain outfalls, removing debris, and locating monitoring points.</td>
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<tr>
<td><strong>Rock Hammer</strong></td>
<td>Can be used to check questionable looking riprap or concrete for soundness. Care must be taken not to break through thin spots or cause unnecessary damage.</td>
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<tr>
<td><strong>Bonker</strong></td>
<td>Is used to determine the condition of support material behind concrete or asphalt faced dams by firmly tapping the surface of the facing material. Concrete fully supported by fill material produces a &quot;click&quot; or &quot;bink&quot; sound, while facing material over a void or hole produces a &quot;clonk&quot; or &quot;bonk&quot; sound. A bonker can be made of 1 1/4-inch hard wood dowel with a metal tip firmly fixed to the tapping end.</td>
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<tr>
<td><strong>Binoculars</strong></td>
<td>Are useful for inspecting limited access areas, especially on concrete dams.</td>
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<tr>
<td><strong>Volume Container and Timer</strong></td>
<td>Are used to make accurate measurements of the rate of leakage. Various container sizes may be required, depending on the flow rates.</td>
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<tr>
<td><strong>Stakes and Flagging Tape</strong></td>
<td>Are used to mark areas requiring future attention and to stake the limits of existing conditions, such as cracks and wet areas, for future comparison.</td>
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<td><strong>Waterproof Boots</strong></td>
<td>Are recommended for inspecting areas of the site where standing water is present.</td>
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<td><strong>Bug Repellent</strong></td>
<td>Is recommended during warm weather. Biting bugs can reduce the efficiency and effectiveness of the inspector.</td>
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<tr>
<td><strong>First Aid Kit</strong></td>
<td>Is particularly recommended for inspections in areas where rattlesnakes or other poisonous snakes might be present.</td>
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</table>
Following a consistent sequence lessens the chance of an important condition being overlooked. Reporting inspection results in the same sequence is recommended to ensure consistent records. Inspection forms are included in Appendix A. The forms should be supplemented with additional details specific to a given dam.

**Record Keeping** - A dated report should be filled out for each inspection, and should be filed along with any photographs taken (which should also be dated). In addition to inspection observations, monitoring measurements and weather conditions (especially recent rains, extended dry spells and snow cover) should also be systematically recorded and included in the inspection report.

Immediately following an inspection, observations should be compared with previous records to see if there are any trends that may indicate developing problems. If a questionable change or trend is noted, and failure is not imminent, a dam owner should consult a professional engineer experienced in dam safety. Quick reaction to questionable conditions will ensure the safety and long life of a dam and possibly prevent costly repairs.

**Crucial Inspection Times** - There are at least five special times when an inspection is recommended regardless of the regular schedule.

1. Prior to a predicted major rainstorm or heavy snow melt; check spillway, outlet channel, and riprap.
2. During or after a severe rainstorm; check spillway, outlet channel, and riprap.
3. During or following a severe windstorm; check riprap performance during the storm (if possible) and again after the storm has subsided.
4. Following an earthquake in the area; make a complete inspection immediately after the event and weekly inspections for the next several months to detect any delayed effects.
5. During and immediately after the first reservoir filling; schedule a regular program of frequent complete inspections during the period a reservoir is first being filled to assure that design and site conditions are as predicted. In most states, an inspection and filling schedule are prescribed by the design engineer and approved by the state engineer.

### 5.3 Embankment Dams and Structures

Embankment dams constitute the majority of structures in place in the U.S. Table 5.1 presents a general directory of embankment features to be inspected and the conditions to look for. The major features include:

- **Upstream slope**
- **Downstream slope**
- **Crest**
- **Seepage areas**

Many of the principles and guidelines presented in this section are also applicable to concrete structures.

#### 5.3.1 Upstream Slope - Typically, major problems encountered on an upstream slope are:

- **Cracks**
- **Slides**
- **Cave-ins or sink holes**
- **Severe erosion**

The first three conditions may indicate serious problems within the embankment. Severe erosion obviously can weaken the structure. An upstream slope should receive a close inspection because riprap and high water levels can hide problems. (When walking on riprap, caution should be used to avoid personal injury.) When a reservoir is emptied, the exposed slope should be thoroughly inspected for settlement areas, root activity, sink holes, or slides. Also, the reservoir basin (bottom of the reservoir) should be inspected for cave-ins or sink holes.

Again, most importantly, a cross path should be used when inspecting the slope so that cracks and slides can be easily identified. In many instances, sighting along the water line alignment will indicate a change in uniformity of the slope; an inspector should stand at one end of the dam and sight along the water line checking for straightness and uniformity. If a crack is seen, the crest and downstream slope in its immediate area should be carefully inspected.

Cracks indicate possible foundation movement, embankment failure, or a surface slide. Locating them can be difficult. Cracks can be less than an inch in width, but still several feet deep. Cracks 1 foot deep usually are not produced by drying and usually are cause for concern. A line of recently dislodged riprap on an upstream slope could indicate a crack below the riprap.

Slides can be almost as difficult to detect as cracks. When a dam is constructed the slopes may not be uniformly graded. Familiarity with the slope configuration at the end of construction can help identify subsequent slope movements. Moreover, the appearance of slides may be subtle; for example, they may produce only about 2 feet of settlement or bulging in a distance of 100 feet or more, yet this would still be a significant amount of settlement. Dated photographs are particularly helpful in detecting such changes.

Sink holes or cave-ins result from internal erosion of the dam - a very serious condition for earthen embankments. The internal erosion, or piping, may be reflected by turbid seepage water on exit. Surface soil materials may be eroded by wave action, rain runoff, and burrow activities. If allowed to continue, the embankment thickness can be reduced and the structure weakened.

#### 5.3.2 Downstream Slope - A downstream slope should be inspected carefully because it is the area where evidence of developing problems appears most frequently. To assure adequate inspection, this area should be kept free from obscuring weeds, brush, or trees.

When cracks, slides or seepage are noted in the downstream slope, the designated dam safety authorities should be notified immediately.

On the downstream slope, some of the more threatening conditions that could be identified are:

- **Cracks**
- **Slides**
- **Seepage**

Cracks can indicate settlement, drying and shrinkage, or the development of a slide. Whatever the cause, cracks should be monitored and changes in length and width noted. Drying cracks may appear and disappear seasonally and normally will not show vertical displacement as will settlement cracks or slide cracks.

Slides require immediate detailed evaluation. Early warning signs include a bulge in the embankment near the toe of a dam or vertical dis-
placement in the upper portion of an embankment.

Seepage is discussed separately below.

If any of these three conditions are seen or suspected, the state engineer’s office should be notified immediately. If a downstream slope is covered with heavy brush or vegetation, a more concerted search must be made.

5.3.3 Crest - A dam's crest usually provides the primary access for inspection and maintenance. Because surface water will pond on a crest unless that surface is well maintained, this part of a dam usually requires periodic regrading. However, problems found on the crest should not be simply graded over or covered up. When a questionable condition is found, the state’s dam safety engineers should be notified immediately.

On the crest, some of the more threatening conditions that may be identified are:

- Longitudinal cracking
- Transverse cracking
- Misalignment

Longitudinal cracking can indicate localized instability, differential settlement, and/or movement between adjacent sections of the embankment. Longitudinal cracking is typically characterized by a single crack or a close, parallel system of cracks along the crest in a direction more or less parallel to the axis of the dam. These cracks, which are usually continuous over their length and are usually greater than 1 foot deep, can be differentiated from drying cracks which are usually intermittent, erratic in pattern, shallow, very narrow, and numerous.

Longitudinal cracking can precede vertical displacement as a dam attempts to adjust to a position of greater stability. Vertical displacements on the crest are usually accompanied by displacements on the upstream or downstream face of a dam.

Transverse cracking can indicate differential settlement or movement between adjacent segments of a dam. Transverse cracking is usually a single crack or a close, parallel system of cracks which extend across the crest in a direction more or less perpendicular to the length of a dam.

This type of cracking is usually greater than 1 foot in depth.

Transverse cracking poses a definite threat to the safety and integrity of a dam. If a crack should progress to a point below the reservoir water surface elevation, seepage could progress along the crack and through the embankment causing severe erosion and if not corrected, leading to failure of the dam.

Misalignment can indicate relative movement between adjacent portions of a dam - generally in directions perpendicular to the axis of the dam. Excessive settlement of dam material and/or the foundation can also cause misalignment. Most problems are usually detectable during close inspection. Misalignment may, however, only be detectable by viewing a dam from either abutment. If on close inspection, the crest appears to be straight for the length of the structure, alignment can be further checked by standing away from the dam on either abutment and sighting along the upstream and downstream edges of the crest. On curved dams, alignment can be checked by standing at either end of a short segment of the dam and sighting along the crest's upstream and downstream edges, noting any curvature or misalignment in that section.

5.3.4 Seepage areas - As discussed previously, although all dams have some seepage, seepage in any area on or near a dam can be dangerous, and all seepage should be treated as a potential problem. Wet areas downstream from dams are not usually natural springs, but seepage areas. Seepage must be controlled in both velocity and quantity. High velocity flows through a dam can cause progressive erosion and, ultimately, failure. Saturated areas of an embankment or abutment can move in massive slides and thus also lead to failure.

Seepage can emerge anywhere on the downstream face of a dam, beyond the toe, or on the downstream abutments at elevations below normal reservoir levels. A potentially dangerous condition exists when seepage appears on the downstream face above the toe of a dam. Seepage on the downstream slope can cause a slide or failure of the dam by internal erosion (piping). Evidence of seepage may vary from a soft, wet area to a flowing spring, and may appear initially as only an area where vegetation is lush and dark green in color. Cattails, reeds, mosses, and other marsh vegetation often become established in seepage areas. Downstream abutment areas should always be inspected closely for signs of seepage, as should the area of contact between an embankment and a conduit spillway; drain, or other appurtenant structures and outlets. Slides in the embankment or an abutment may be the result of seepage causing soil saturation and high pore pressures.

Since seepage can be present but not readily visible, an intensive search should be made of all downstream areas where seepage water might emerge. Even in short grass cover, seepage may not be visible and must be walked on to be found. Ideally, an inspection for seepage should be made when a reservoir is full.

5.4 CONCRETE DAMS AND STRUCTURES

From a safety standpoint, the principal advantage of concrete dams over earth dams is their relative freedom from failure by erosion during overtopping as well as from embankment slides and piping failures.

Although concrete dams comprise a minority of all dams, they are commonly of greater height and storage capacity than earth structures. Thus, they often represent a potentially greater hazard to life and property. It is important that concrete dam owners be aware of the principal modes of failure of such dams and that they be able to discern between conditions which threaten the safety of the dam and those which merely indicate a need for maintenance.

Concrete dams fail for reasons that are significantly different from earth dams. Some include:

- Structural cracks
- Foundation and abutment weakness
- Deterioration due to alkali-aggregate reaction

Should any of these conditions be discovered during inspection, an owner should obtain engineering assistance immediately.

Structural cracks occur when portions of the dam are overstressed and are the result of inadequate design, poor construction or faulty materials. Structural cracks are often irregular,
may run at an angle to the major axes of the dam and may exhibit abrupt changes in direction. These cracks can also have noticeable radial, transverse, or vertical displacement. Concrete dams transfer a substantial load to the abutments and foundation. Although the concrete of a dam may endure, the natural abutments or foundation may crack, crumble, or move in a massive slide. If this occurs, support for the dam is lost, and it fails. Impending failure of the foundation or abutments may be difficult to detect because initial movements are often very small.

Severe deterioration can result from a chemical reaction between alkali present in cements and certain forms of silica present in some aggregates. This chemical reaction produces byproducts of silica gels which cause expansion and loss of strength within concrete. Alkali reaction is characterized by certain observable conditions such as cracking (usually a random pattern on a fairly large scale), and by excessive internal and overall expansion. Additional indications include the presence of a gelatinous exudation or whitish amorphous deposits on the surface, and a chalky appearance of freshly fractured concrete.

The alkali-aggregate reaction takes place in the presence of water. Surfaces exposed to the elements or dampened by seepage will deteriorate most rapidly. Once suspected, the condition can be confirmed by a series of tests performed on concrete samples drilled from a dam. Although the deterioration is gradual, alkali-aggregate reaction cannot be economically corrected by any means now known. Continued deterioration may require total replacement of a structure.

Inspection of a concrete dam is similar to that of an earth dam. However, the following additional items should be considered:

- Access and safety
- Monitoring
- Outlet system
- Cracks at construction and expansion joints
- Shrinkage cracks
- Deterioration due to spalling
- Minor leakage

Access and safety are important because the faces of concrete dams are often nearly vertical, and sites are commonly steep-walled rock canyons. Access to the downstream face, toe area, and abutments of such dams may be difficult and require special safety equipment such as safety ropes, or a boatswain's chair. Concrete dams pose a special problem for the dam owner because of the difficulty in gaining close access to the steep surfaces. Regular inspection with a pair of powerful binoculars can initially identify areas where change is occurring. When these changes are noted, a detailed close-up inspection should be conducted. Close inspection of the upstream face may also require a boatswain's chair or a boat.

Monitoring helps detect structural problems in concrete dams such as cracks in the dam, abutments, or foundation. Cracks may develop slowly at first, making it difficult to determine if they are widening or otherwise changing over time. If a structural crack is discovered, it should be monitored for changes in width, length, and offset, and a monitoring network of instruments should be installed and read on a regular basis.

Outlet system deterioration is a problem for all dams but the frequency of such damage may be higher in concrete dams because of their greater average hydraulic pressure. Thus, outlet system inspection should be emphasized for large concrete dams.

Cracks at construction joints exist because concrete dams are built in segments, while expansion joints are built into dams to accommodate volumetric changes which occur in the structures after concrete placement. The latter are referred to as "designed" cracks. These joints are typically constructed so that no bond or reinforcing, except non-bonded waterstops and dowels, extend across the joints.

Shrinkage cracks often occur when, during original construction, irregularities or pockets in the abutment contact are filled with concrete and not allowed to fully cure prior to placement of adjacent portions of the dam. Subsequent shrinkage of the concrete may lead to irregular cracking at or near the abutment.

Shrinkage cracks are also caused by temperature variation. During winter months, the upper portion of a dam may become significantly colder than those portions which are in direct contact with reservoir water. This temperature differential can result in cracks which extend from the crest for some distance down each face of the dam. These cracks will probably occur at construction or expansion joints, if these are provided.

Shrinkage cracks can be a sign that certain portions of the dam are not carrying the design load. In such cases, the total compression load must be carried by a smaller percentage of the structure. It may be necessary to restore load-carrying capability by grouting affected areas. This work requires the assistance of an engineer.

Spalling is the process by which concrete chips and breaks away as a result of freezing and thawing. Almost every concrete dam in colder climates experiences continued minor deterioration due to spalling. Because it usually affects only the surface of a structure, it is not ordinarily considered dangerous. However, if allowed to continue, spalling can result in structural damage, particularly if a dam is of thin cross section. Also, repair is necessary when reinforcing steel becomes exposed. The method of repair of spalled areas depends upon the depth of the deterioration. In severe situations, engineering assistance is required.

Minor leakage through concrete dams, although unsightly, is not usually dangerous, unless accompanied by structural cracking. The effect may be to promote deterioration due to freezing and thawing. However, increases in seepage could indicate that, through chemical action, materials are being leached from the dam and carried away by the flowing water. Dam owners should note that decreases in seepage could also occur as mineral deposits are formed in portions of the seepage channel. In either case, the condition is not inherently dangerous and detailed study is required before it can be determined if repair is necessary for other than cosmetic reasons.
5.5 SPILLWAYS

As detailed in Chapter 2, the main function of a spillway is to provide a safe exit for excess water in a reservoir. If a spillway is of inadequate size, a dam could be overtopped and fail. Similarly, defects in a spillway can cause failure by rapid erosion. A spillway should always be kept free of obstructions, have the ability to resist erosion, and be protected from deterioration. Because dams represent a substantial investment and spillways make up a major part of dam costs, a conscientious annual maintenance program should be pursued not only to protect the public but also to minimize costs as well.

The primary problems encountered with spillways include:

- Inadequate capacity
- Obstructions
- Erosion
- Deterioration
- Cracks
- Undermining of spillway outlet

Inadequate capacity is determined by several factors, such as drainage area served, magnitude or intensity of storms in the watershed, storage capacity of the reservoir, and the speed with which rain water flows into and fills the reservoir. An inadequate spillway can cause the water in a reservoir to overtop the dam.

Obstructions of a spillway may result from excessive growth of grass and weeds, thick brush, trees, debris, or landslide deposits. An obstructed spillway can have a substantially reduced discharge capacity which can lead to overtopping of the dam. Grass is usually not considered an obstruction; however, tall weeds, brush, and young trees should be periodically cleared from spillways. Similarly, any substantial amount of soil deposited in a spillway — whether from sloughing, landslide or sediment transport — should be immediately removed. Timely removal of large rocks is especially important, since they can obstruct flow and encourage erosion.

Erosion of a spillway may occur during a large storm when large amounts of water flow for many hours. Severe damage of a spillway or complete wash-out can result if the spillway cannot resist erosion. If a spillway is excavated out of a rock formation or lined with concrete, erosion is usually not a problem. However, if a spillway is excavated in sandy soil, deteriorated granite, clay, or silt deposits, erosion protection is very important. Generally, resistance to erosion can be increased if a spillway channel has a mild slope, or if it is covered with a layer of grass or riprap with bedding material.

A spillway cannot be expected to perform properly if it has deteriorated. Examples include: collapse of side slopes, riprap, concrete lining, approach section, the chute channel, the stilling basin, the discharge channel, or protective grass cover. These problems can cause water to flow under and around the protective material and lead to severe erosion. Remedial action must be taken as soon as any sign of deterioration has been detected.

Drying cracks in an earth spillway channel are usually not regarded as a functional problem. However, missing rocks in a riprap lining can be considered a “crack” in the protective cover, and must be repaired at once. Cracks in concrete lining of a spillway are commonly encountered. These cracks may be caused by uneven foundation settlement, shrinkage, slab displacement, or excessive earth or water pressure. Large cracks will allow water to wash out fine material below or behind the concrete slab, causing erosion, more cracks, and even severe displacement of the slab. The slab may even be dislodged and washed away by the flow. A severely cracked concrete spillway should be examined by and repaired under the supervision of an engineer.

Undermining of a spillway causes erosion at a spillway outlet, whether it be a pipe or overflow spillway, is one of the most common spillway problems. Severe undermining of the outlet can displace sections of pipe, cause slides in the downstream embankment of the dam and eventually lead to complete failure of a dam. Water must be conveyed safely from the reservoir to a point downstream of the dam without endangering the spillway itself or the embankment. Often the spillway outlet is adequately protected for normal flow conditions, but not for extreme flows. It is easy to misestimate the energy and force of flowing water and the resistance of outlet material (earth, rock, concrete, etc). The required level of protection is difficult to establish by visual inspection but can usually be determined by hydraulic calculations performed by a professional engineer.

Structures that provide complete erosion control at a spillway outlet are usually expensive, but often necessary. Less expensive protection can also be effective, but require extensive periodic maintenance as areas of erosion and deterioration develop.

The following four factors, often interrelated, contribute to erosion at the spillway outlet:

1. Flows emerging from the outlet are above the stream channel. If outlet flows emerge at the correct elevation, tailwater in the stream channel can absorb a substantial amount of the high velocity, flow and the hydraulic energy will be contained in the stilling basin.

2. Flows emerging from the spillway are generally free of sediment and therefore have substantial sediment-carrying capacity. In obtaining sediment, moving water will scour soil material from the channel and leave eroded areas. Such erosion is difficult to design for and requires protection of the outlet for a safe distance downstream from the dam.

3. Flows leaving the outlet at high velocity can create negative pressures that can cause material to be loosened and removed from the floor and walls of the outlet channel. This action is called “cavitation” when it occurs on concrete or metal surfaces. Venting can sometimes be used to relieve negative pressures.

4. Water leaking through pipe joints and/or flowing along a pipe from the reservoir may weaken the soil structure around the pipe. Inadequate compaction adjacent to such structures during construction can complicate this problem.

Procedure for inspection - Spillway inspection is an important part of a dam safety program. The basic objective of spillway inspection is to detect any sign of obstruction, erosion, deterioration, misalignment, or cracking.

When inspecting an earth spillway, one should determine whether side slopes have sloughed, whether there is excessive vegetation in the channel; and one should look for signs of erosion and rodent activity. One should also use a probe to determine the hardness and moisture content of
the soil, note the location of particularly wet or soft spots, and see if the stilling basin or drop structure is properly protected with rocks or rip-rap. Because some erosion is unavoidable during stilling, an owner should also determine whether such erosion might endanger the embankment itself. If the spillway is installed with a sill, a dam owner should also determine if there are any cracks or misalignment in the sill and check for erosion beneath or downstream of the sill.

Commonly encountered defects of concrete spillways and general inspection procedures for cracks, spalling, drains, joints, and misalignment are summarized in the following paragraphs.

Hairline cracks are usually harmless. Large cracks should be carefully inspected and their location, width, length, and orientation noted. Deterioration should be determined and exposure of reinforcing bars should be watched for.

Spillway surfaces exposed to freeze-thaw cycles often suffer from surface spalling. Chemical action, contamination, and unsound aggregates can also cause spalling. If spalling is extensive, the spalled area should be sketched or photographed, showing the length, width, and depth of the area. The problem should be examined closely to see if the remaining concrete has deteriorated or if reinforcing bars are exposed. The concrete should be tapped with a "bonker" or rock hammer to determine if voids exist below the surface. Shallow spalling should be examined from time to time to determine if it is becoming worse. Deep spalling should be repaired as soon as possible by an experienced contractor.

Walls of spillways are usually equipped with weep (or drain) holes. Occasionally spillway chute slabs are also equipped with weep holes. If all such holes are dry, the soil behind the wall or below the slab is probably dry. If some holes are draining while others are dry, the dry holes may be plugged by mud or mineral deposits. Plugged weep holes increase the chances for failure of retaining walls or chute slabs. The plugged holes should be probed to determine causes of blockage and soil or deposits cleaned out to restore drainage. If this work is not successful, rehabilitation should be performed as soon as possible under the supervision of a professional engineer.

Spillway retaining walls and chute slabs are normally constructed in sections. Between adjoining sections, gaps or joints must be tightly sealed with flexible materials such as tar, epoxies, or other chemical compounds. Sometimes rubber or plastic diaphragm materials or copper foil are used to obtain watertightness. During inspection, one should note the location, length, and depth of any missing sealant, and probe open gaps to determine if soil behind the wall or below the slab has been undermined.

Misalignment of spillway retaining walls or chute slabs may be caused by foundation settlement or earth or water pressure. The inspector should carefully look at the upstream or downstream end of a spillway near the wall to determine if it has been tipped inward or outward. Relative displacement or offset between neighboring sections can be readily identified at joints. The horizontal as well as vertical displacement should be measured. A fence on top of the retaining wall is usually erected in a straight line at the time of construction; thus any curve or distortion of the fence line may indicate wall deformation.

At the time of construction, the entire spillway chute should form a smooth surface. Thus, measurement of relative movement between neighboring chute slabs at joints will give a good indication of slab displacement. Misalignment or displacement of walls or, the slab is often accompanied by cracks. A clear description of crack patterns should be recorded or photos taken to help in understanding the nature of the displacement.

5.6 Inlets, Outlets, and Drains

A dam's inlet and outlet works, including internal drains, are essential to the operation of a dam. Items for inspection and special attention include:

- Reservoir pool levels
- Lake drains and internal drains
- Corrosion
- Trash racks on pipe spillways
- Cavitation

The topics discussed above for spillways also are relevant.

Reservoir pool levels - Reservoir pool levels are controlled by spillway gates, lake drain and release structures, or flashboards. Flashboards are sometimes used to permanently or temporarily raise the pool level of water supply reservoirs. Flashboards should not be installed or allowed unless there is sufficient freeboard remaining to safely accommodate a design flood. Pool level draw down should not exceed about 1 foot per week for slopes composed of clay or silt materials except in emergency situations. Very flat slopes or slopes with free-draining upstream soils can, however, withstand more rapid draw down rates. Conditions causing or requiring temporary or permanent adjustment of the pool level include:

- Development of a problem which requires that the pool be lowered. Drawdown is a temporary solution until the problem is solved.
- Release of water downstream to supplement stream flow during dry conditions.
- Fluctuations in the service area's demand for water.
- Repair of boat docks in the winter and growth of aquatic vegetation along the shoreline.
- Requirements for recreation, hydropower, or water fowl and fish management.

Lake drains - A lake drain should always be operable so that the pool level can be drawn down in case of an emergency or for necessary repair. Lake drain valves or gates that have not been operated for a long time can present a special problem for owners. If the valve cannot be closed after it is opened, the impoundment could be completely drained. An uncontrolled and rapid drawdown could also cause more serious problems such as slides along the saturated upstream slope of the embankment or downstream
flooding. Therefore, when a valve or gate is operated, it should be inspected and all appropriate parts lubricated and repaired. It is also prudent to advise downstream residents of large and/or prolonged discharges.

To test a valve or gate without risking complete drainage, one must physically block the drain inlet upstream from the valve. Some drains have been designed with this capability and have dual valves or gates, or slots for stoplogs (sometimes called bulkheads) upstream from the valve. Otherwise, divers can be hired to inspect the drain inlet and may be able to construct a temporary block at the inlet.

Other problems may be encountered when operating a lake drain. Sediment can build up and block the drain inlet, or debris can enter the valve chamber, hindering its function. The likelihood of these problems is greatly decreased if the valve or gate is operated and maintained periodically.

Corrosion - Corrosion is a common problem of pipe spillways and other conduits made of metal. Exposure to moisture, acid conditions, or salt will accelerate corrosion. In particular, acid runoff from strip mine areas will cause rapid corrosion of steel pipes. In such areas, pipes made of non-corrosive materials such as concrete or plastic should be used. Metal pipes which have been coated to resist accelerated corrosion are also available. The coating can be of epoxy, aluminum, zinc (galvanization), asbestos or mortar. Coatings applied to pipes in service are generally not very effective because of the difficulty of establishing a bond. Similarly, bituminous coating cannot be expected to last more than one to two years on flowways. Of course, corrosion of metal parts of operating mechanisms can be effectively treated and prevented by keeping those parts greased and/or painted.

Corrosion can also be controlled or arrested by installing cathodic protection. A metallic anode made out of a material such as magnesium is buried in the soil and is connected to the metal pipe by wire. An electric potential is established which causes the magnesium to corrode and not the pipe.

Trash on pipe spillways - Many dams have pipe and riser spillways. As with concrete spillways, pipe inlets that become plugged with debris or trash reduce spillway capacity. As a result, the potential for overtopping is greatly increased, particularly if there is only one outlet. If a dam has an emergency spillway channel, a plugged principal spillway will cause more frequent and greater than normal flow in the emergency spillway. Because emergency spillways are generally designed for infrequent flows of short duration, serious damage may result. For these reasons trash collectors or racks should be installed at the inlets to pipe spillways and lake drains.

A well-designed trashrack will stop large debris that could plug a pipe but allow unrestricted passage of water and smaller debris. Some of the most effective racks have submerged openings which allow water to pass beneath the trash into the riser inlet as the pool level rises. Openings that are too small will stop small debris such as twigs and leaves, which in turn will cause a progression of larger items to build up, eventually completely blocking the inlet. Trashrack openings should be at least 6 inches across regardless of the pipe size. The larger the principal spillway conduit, the larger the trashrack opening should be. The largest possible openings should be used, up to a maximum of about 2 feet.

A trashrack should be properly attached to the riser inlet and strong enough to withstand the forces of fast-flowing debris, heavy debris, and ice. If the riser is readily accessible, vandals may throw riprap stone into it. The size of the trashrack openings should not be decreased to prevent this. Instead rock that is larger than the trashrack openings or too large to handle should be used for riprap.

Maintenance should include periodic checking of the rack for rusted and broken sections and repair as needed. The trashrack should be checked frequently during and after storms to ensure that it is functioning properly and to remove accumulated debris.

Cavitation - When water flows through an outlet system and passes restrictions (e.g., valves), a pressure drop may occur. If localized water pressures drop below the vapor pressure of water, a partial vacuum is created and the water actually boils, causing shockwaves which can damage the outlet pipes and control valves. This process can be a serious problem for large dams where discharge velocities are high.

Testing the outlet system - All valves should be fully opened and closed at least once a year. This not only limits corrosion buildup on control stems and gate guides, but also provides an opportunity to check for smooth operation of the system. Jerky or erratic operation could signal problems, and indicate the need for more detailed inspection.

The full range of gate settings should be checked. The person performing the inspection should slowly open the valve, checking for noise and vibration - certain valve settings may result in greater turbulence. He or she should also listen for noise which sounds like gravel being rapidly transported through the system. This sound indicates that cavitation occurring, and these gate settings should be avoided. The operation of all mechanical and electrical systems, backup electric motors, power generators, and power and lighting wiring associated with the outlet should also be checked.

Inspecting the outlet system - Accessible portions of the outlet, such as the outfall structure and control, can be easily and regularly inspected. However, severe problems are commonly associated with deterioration or failure of portions of the system which are either buried in the dam or normally under water.

Areas to be inspected include:

- Outlet pipes 30 inches or greater in diameter can be inspected internally, provided the system has an upstream valve allowing the pipe to be emptied. Tapping the conduit interior with a hammer can help locate voids behind the pipe. This type of inspection should be performed at least once a year.

- Small diameter outlet pipes can be inspected by remote TV camera if necessary. The camera is channeled through the conduit and transmits a picture back to an equipment truck. This type of inspection is expensive and usually requires the services of an engineer. However, if no other method of inspection is possible, inspection by TV is recommended at least once every five years.
Outlet intake structures, wet wells, and outlet pipes with only downstream valves are the most difficult dam appurtenances to inspect because they are usually under water. These should be inspected whenever the reservoir is drawn down or at five year intervals. If a definite problem is suspected, or if the reservoir remains full over extended periods, divers should be hired to perform an underwater inspection.

5.7 OTHER AREAS
Other areas requiring inspection include:
- Mechanical and electrical systems
- Reservoir surface and shoreline
- Upstream watershed
- Downstream floodplains

Mechanical equipment includes spillway gates, sluice gates or valves for lake drains or water supply pipes, stoplogs, sump pumps, flashboards, relief wells, emergency power sources, siphons, and other devices. All mechanical and associated electrical equipment should be operated at least once a year and preferably more often. The test should cover the full operating range of the equipment under actual operating conditions. Each operating device should be permanently marked for easy identification, and all operating equipment should be kept accessible. All controls should be checked for proper security to prevent vandalism, and finally, all operating instructions should be checked for clarity and maintained in a secure, but readily accessible location.

The reservoir surface and shoreline should be inspected to identify possible problems away from the actual structure. Whirlpools can indicate submerged outlets. Large land slides coming into the reservoir could cause waves overtopping the dam.

Floods arise from the upstream watershed. Therefore, characteristics of the watershed, such as impervious areas (e.g. parking lots), relate directly to the magnitude of a flood. Urban development in a watershed can increase the size of flood peaks and the volume of runoff, thereby making a previously acceptable spillway inadequate. Awareness of upstream development and other factors which might influence reservoir inflows is important in order to anticipate possible problems and necessary or modifications in the dam.

Development in downstream floodplains is also very important to the dam owner as the extent of development and flood preparedness relate directly to loss of life and damages should the dam fail.
**INSPECTION GUIDELINES**

**EMBANKMENT UPSTREAM SLOPE**

**PROBLEM**

**SINKHOLE**

- **PROBABLE CAUSE**
  Piping or internal erosion of embankment materials or foundation causes a sinkhole. The cave-in of an eroded cavern can result in a sink hole. A small hole in the wall of an outlet pipe can develop a sink hole. Dirty water at the exit indicates erosion of the dam.

- **POSSIBLE CONSEQUENCES**
  HAZARDOUS
  Piping can empty a reservoir through a small hole in the wall or can lead to failure of a dam as soil pipes erode through the foundation or a previous part of the dam.

- **RECOMMENDED ACTIONS**
  Inspect other parts of the dam for seepage or more sink holes. Identify exact cause of sink holes. Check seepage and leakage outflows for dirty water. A qualified engineer should inspect the conditions and recommend further actions to be taken.

**LARGE CRACKS**

- **PROBABLE CAUSE**
  A portion of the embankment has moved because of loss of strength, or the foundation may have moved, causing embankment movement.

- **POSSIBLE CONSEQUENCES**
  HAZARDOUS
  Indicates onset of massive slide or settlement caused by foundation failure.

- **RECOMMENDED ACTIONS**
  Depending on embankment involved, draw reservoir level down. A qualified engineer should inspect the conditions and recommend further actions to be taken.

**SLIDE, SLUMP OR SLIP**

- **PROBABLE CAUSE**
  Earth or rocks move down the slope along a slippage surface because of too steep a slope, or the foundation moves. Also, look for slide movement in reservoir basin.

- **POSSIBLE CONSEQUENCES**
  HAZARDOUS
  A series of slides can lead to obstruction of the outlet or failure of the dam.

- **RECOMMENDED ACTIONS**
  Evaluate extent of the slide. Monitor slide. (See Chapter 6.) Draw the reservoir level down if safety of dam is threatened. A qualified engineer should inspect the conditions and recommend further actions to be taken.

**SCARPS, BENCHES, OVERSTEEP AREAS**

- **PROBABLE CAUSE**
  Wave action, local settlement, or ice action cause soil and rock to erode and slide to the lower part of the slope forming a bench.

- **POSSIBLE CONSEQUENCES**
  Erosion lessens the width and possible height of the embankment and could lead to increased seepage or overtopping of the dam.

- **RECOMMENDED ACTIONS**
  Determine exact cause of scarps. Do necessary earthwork, restore embankment to original slope and provide adequate protection (sealing and riprap). See Chapter 7.
Problem

Broken Down
Missing Riprap

Probable Cause

Poor quality riprap has deteriorated. Wave action or ice action has displaced riprap. Round and similar-sized rocks have rolled downhill.

Possible Consequences

Wave action against these unprotected areas decreases embankment width.

Recommend Actions

Re-establish normal slope. Place bedding and competent riprap. (See Chapter 7.)

Figure 5.3.2
Inspection Guidelines - Downstream Slope

Erosion Behind Poorly Graded Riprap

Probable Cause

Similar-sized rocks allow waves to pass between them and erode small gravel particles and soil.

Possible Consequences

Soil is eroded away from behind the riprap. This allows riprap to settle, providing less protection and decreased embankment width.

Recommend Actions

Re-establish effective slope protection. Place bedding material. Engineer required for design for gradation and size for rock for bedding and riprap. A qualified engineer should inspect the conditions and recommend further actions to be taken.

Slide/Sloough

Probable Cause

1. Lack of or loss of strength of embankment material.
2. Loss of strength can be attributed to infiltration of water into the embankment or loss of support by the foundation.

Possible Consequences

1. Measure extent and displacement of slide.
2. If continued movement is seen, begin lowering water level until movement stops.
3. Have a qualified engineer inspect the condition and recommend further action. Engineer required.

HAZARDOUS

Massive slide cuts through crest or upstream slope reducing streambed and cross section. Structural collapse or overtopping can result.
**PROBLEM**

**TRANSVERSE CRACKING**

Problems associated with transverse cracking include:
- Differential settlement of the embankment, leading to transverse cracking (e.g., center settles more than embankment).

**CAVE IN/COLLAPSE**

Problems associated with cave in/collapse include:
1. Lack of adequate compaction.
2. Rodent holes below.
3. Piping through embankment or foundation.

**LONGITUDINAL CRACKING**

Problems associated with longitudinal cracking include:
1. Drying and shrinkage of surface material.
2. Downslope movement of settlement of embankment.

**SLUMP** (LOCALIZED CONDITION)

Problems associated with slumps include:
- Preceded by erosion undermining a portion of the slope. Can also be found on steep slopes.

**PROBABLE CAUSE**

- Tilt resulting from uneven settlement of the embankment, also leads to transverse cracking (e.g., center settles more than embankment).
- Lack of adequate compaction.
- Rodent holes below.
- Piping through embankment or foundation.
- Drying and shrinkage of surface material.
- Downslope movement of settlement of embankment.

**POSSIBLE CONSEQUENCES**

- **HAZARDOUS**
  - Settlement or shrinkage cracks can lead to seepage of reservoir water through the dam.
  - Shrinkage cracks allow water to enter the embankment, which promotes saturation and increases freeze-thaw action.
  - Indicates possible washout of embankment.
  - Indicates possible washout of embankment.
  - Can be an early warning of a potential slide.
  - Shrinkage cracks allow water to enter the embankment, which further cracks the embankment.
  - Settling or slide showing loss of strength in embankment can lead to failure.
  - Can expose impervious zone to erosion and lead to further slumps.

**RECOMMENDED ACTIONS**

1. If necessary, plug upstream end of crack to prevent flows from the reservoir.
2. A qualified engineer should inspect the conditions and recommend further actions to be taken.

**ENGINEER REQUIRED**
**PROBLEM**

**EROSION**

Water from intense rainfall or snow-melt carries surface material down the slope, resulting in continuous washouts.

**PROBABLE CAUSE**

**POSSIBLE CONSEQUENCES**

Can be hazardous if allowed to continue. Erosion can lead to eventual deterioration of the downstream slope and failure of the structure.

**RECOMMENDED ACTIONS**

1. The preferred method to protect eroded areas is rock or riprap.
2. Re-establishing protective grasses can be adequate if the problem is detected early.

**TREES/OBSCURING BRUSH**

Natural vegetation in area.

Large tree roots can create seepage paths. Bushes can obscure visual inspection and harbor rodents.

1. Remove all large, deep-rooted trees and shrubs on or near the embankment. Properly backfill void. (See Chapter 7.)
2. Control vegetation on the embankment that obscures visual inspection. (See Chapter 7.)

**RODENT ACTIVITY**

Over-abundance of rodents. Holes, tunnels, and cavities are caused by animal burrowing. Certain habitats like cartilaginous plants, and trees close to the reservoir encourage these activities.

Can reduce length of seepage paths, and lead to piping failure. If tunnel extends through most of the dam, it can lead to failure of the dam.

1. Control rodents to prevent more damage.
2. Backfill existing rodent holes.
3. Remove rodents. Determine exact location of digging and extend of tunnelling. Remove habitats and repair damages. (See Chapter 7.)

**LIVESTOCK/CATTLE TRAFFIC**

Excessive travel by livestock especially harmful to slopes when wet.

Cuts areas back of erosion protection and causes erosion channels. Allows water to stand. Areas susceptible to drying cracks.

1. Fence livestock outside embankment area.
2. Repair erosion protection, i.e., riprap, grass.
PROBLEM

LONGITUDINAL CRACK

1. Uneven settlement between adjacent sections or zones of the embankment.
2. Foundation failure causing loss of support to embankment.
3. Initial stages of embankment slide.

PROBABLE CAUSE

VERTICAL DISPLACEMENT

1. Vertical movement between adjacent sections of the embankment.
2. Structural deformation or failure caused by structural stress or instability, or by failure of the foundation.

POSSIBLE CONSEQUENCES

HAZARDOUS

1. Creates local area of low strength within embankment, could be the point of initiation of future structural movement, deformation, or failure.
2. Provides entrance point for surface run-off into embankment, allowing saturation of adjacent embankment area, and possible lubrication which could lead to localized failure.

POSSIBLE CONSEQUENCES

HAZARDOUS

1. Protein local area of low strength within embankment which could cause future movement.
2. Leads to structural instability or failure.
3. Provides entrance point for surface water that could further lubricate failure plane.
4. Reduces available embankment cross section.

RECOMMENDED ACTIONS

HAZARDOUS

1. Carefully inspect crack and carefully record location, length, depth, width, alignment, and other pertinent physical features, immediately stake out limits of cracking, Monitor frequency.
2. Engineer should determine cause of cracking and supervise steps necessary to reduce danger to dam and correct condition.
3. Effectively seal the cracks at the cracks at the crest's surface to prevent infiltration by surface water.
4. Continue to routinely monitor crest for evidence of further cracking.

ENGINEER REQUIRED

CAVE-IN ON CREST

1. Rodent activity.
2. Hole in outlet conduit is causing erosion of embankment material.
3. Internal erosion or piping of embankment material by seepage.
4. Breakdown of dispersive clays within embankment by seepage waters.

HAZARDOUS

1. Void within dam could cause localized failure, sloughing, instability, or reduced embankment cross section.
2. Entrance point for surface water.

RECOMMENDED ACTIONS

HAZARDOUS

1. Carefully inspect hole and record location and physical characteristics (depth, width, length) of cave in.
2. Engineer should determine cause of cave in and supervise all steps necessary to reduce threat to dam and correct condition.
3. Excavate cave in, slope sides of excavation, and backfill hole with competent material using proper construction techniques. (See Chapter 7.) This should be supervised by engineer.

ENGINEER REQUIRED
**PROBLEM**

**TRANSVERSE CRACKING**

1. Uneven movement between adjacent segments of the embankment.
2. Deformation caused by structural stress or instability.

**PROBABLE CAUSE**

1. Movement between adjacent parts of the structure.
2. Uneven deflection of dam under loading by reservoir.
3. Structural deformation or failure near area of misalignment.

**POSSIBLE CONSEQUENCES**

**HAZARDOUS**

1. Area of misalignment is usually accompanied by low area in crest which reduces freeboard.
2. Can produce local areas of low embankment strength which may lead to failure.

**RECOMMENDED ACTIONS**

1. Establish monuments across crest to determine exact amount, location, and extent of misalignment.
2. Engineer should determine cause of misalignment and supervise all steps necessary to reduce threat to dam and correct condition.
3. Monitor crest monuments on a scheduled basis following remedial action to detect possible future movement. (See Chapter 6.)

**ENGINEER REQUIRED**

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**CREST MISALIGNMENT**

1. Movement between adjacent parts of the structure.
2. Uneven deflection of dam under loading by reservoir.
3. Structural deformation or failure near area of misalignment.

**POSSIBLE CONSEQUENCES**

**HAZARDOUS**

1. Area of misalignment is usually accompanied by low area in crest which reduces freeboard.
2. Can produce local areas of low embankment strength which may lead to failure.

**RECOMMENDED ACTIONS**

1. Establish monuments across crest to determine exact amount, location, and extent of misalignment.
2. Engineer should determine cause of misalignment and supervise all steps necessary to reduce threat to dam and correct condition.
3. Monitor crest monuments on a scheduled basis following remedial action to detect possible future movement. (See Chapter 6.)

**ENGINEER REQUIRED**

---

**LOW AREA IN CREST OF DAM**

1. Excessive settlement in the embankment or foundation directly beneath the low area in the crest.
2. Internal erosion of embankment material.
3. Foundation spreading in upstream and/or downstream direction.
4. Prolonged wind erosion of crest area.
5. Improper final grading following construction.

**POSSIBLE CONSEQUENCES**

**HAZARDOUS**

1. Area of misalignment is usually accompanied by low area in crest which reduces freeboard.
2. Can produce local areas of low embankment strength which may lead to failure.

**RECOMMENDED ACTIONS**

1. Establish monuments along length of crest to determine exact amount, location, and extent of settlement in crest.
2. Engineer should determine cause of low area and supervise all steps necessary to reduce possible threat to dam and correct condition.
3. Re-establish uniform crest elevation over crest length by placing fill in low area using proper construction techniques. This should be supervised by engineer.
4. Re-establish monuments across crest of dam and monitor monuments on a routine basis to detect possible future settlement. (See Chapter 6.)

**ENGINEER REQUIRED**
PROBLEM

OBSCURING VEGETATION
Neglect of dam and lack of proper maintenance procedures.

PROBABLE CAUSE

RODENT ACTIVITY
Burrowing animals.

POSSIBLE CONSEQUENCES

GULLY ON CREST
1. Poor grading and improper drainage of crest. Improper drainage causes surface runoff to collect and drain of crest at low point in upstream or downstream shoulder.
2. Inadequate spillway capacity which has caused dam to overtop.

RECOMMENDED ACTIONS

1. Remove all damaging growth from the dam. This would include removal of trees, bushes, brush, and growth other than grass. Grass should be encouraged on all segments of the dam to prevent erosion by surface runoff. Root systems should also be removed to the maximum practical extent. The void which results from removing the root system should be backfilled with well-compacted material.
2. Future undesirable growth should be removed by cutting or spraying, as part of an annual maintenance program. (See Chapter 7.)
3. All cutting or debris resulting from the vegetation removal should be immediately taken from the dam and properly disposed of outside the reservoir basin.

RUTS ALONG CREST
Heavy vehicle traffic without adequate or proper maintenance or proper crest surfacing.

1. Inhibits easy access to all parts of crest.
2. Allows continued development of rutting.
3. Allows standing water to collect and saturate crest of dam.
4. Operating and maintenance vehicles can get stuck.

1. Drain standing water from rut.
2. Regrade and recompact crest to restore integrity and provide proper drainage to upstream slope. (See Chapter 7.)
3. Provide gravel or rockbase material to accommodate traffic.
4. Do periodic maintenance and regrading to prevent formation of rut.
PROBLEM

PUDDLING ON CREST-
POOR DRAINAGE

POSSIBLE CAUSES

1. Poor grading and improper drainage of
crest.
2. Localized consolidation or settlement on
crest allows puddles to develop.

POSSIBLE CONSEQUENCES

1. Cause localized saturation of the crest.
2. Inhibit access to all parts of the dam and
crest.
3. Becomes progressively worse if not
corrected.

RECOMMENDED ACTIONS

1. Drain standing water from puddles.
2. Regrade and recompact crest to restore
integrity and provide proper drainage to
spillway slope. (See Chapter 7.)
3. Provide gravel or roadbase material to
accommodate traffic.
4. Do periodic maintenance and regrading to
prevent reformation of low areas.

DRIYING CRACKS

MATERIALS ON THE CREST OF DAM EXPAND AND
CONTRACT WITH ALTERNATE WETTING AND DRYING
OF WEATHER CYCLES. DRYING CRACKS ARE USUALLY
SHORT, SHALLOW, NARROW, AND MOTTLED.

Provides point of entrance for surface runoff
and surface moisture, causing saturation of
adjacent embankment areas. This saturation,
and later drying of the dam, could cause
further cracking.

RECOMMENDED ACTIONS

1. Seal surface of cracks with a light, imper-
vious material. (See Chapter 7.)
2. Routinely grade crest to provide proper
drainage and fill cracks. - OR -
3. Cover crest with non-plastic (not clay)
material to prevent large moisture content
variations.
PROBLEM

EXCESSIVE QUANTITY AND/OR MUDDY WATER EXITING FROM A POINT

1. Water has created an open pathway, channel, or pipe through the dam. The water is eroding and carrying embankment material.
2. Large amounts of water have accumulated in the downstream slope. Water and embankment materials are exiting at one point. Surface agitation may be causing the muddy water.
3. Rainfall, frost action or poor construction have allowed water to create an open pathway or pipe through the embankment.

PROBABLE CAUSE

POSSIBLE CONSEQUENCES

HAZARDOUS

1. Continued flow can saturate parts of the embankment and lead to slides in the area.
2. Continued flow can further erode embankment materials and lead to failure of the dam.

RECOMMENDED ACTIONS

1. Begin measuring outflow quantity and establish whether water is getting muddier, starting the same, or clearing up.
2. If quantity of flow is increasing the water level in the reservoir should be lowered until the flow stabilizes or stops.
3. Search for openings on upstream side and plug if possible.
4. A qualified engineer should inspect the condition and recommend further actions to be taken.

ENGINEER REQUIRED

STREAM OF WATER EXITING THROUGH CRACKS NEAR THE CREST

1. Severe drying has caused shrinkage of embankment material.
2. Settlement in the embankment or foundation is causing the transverse cracks.

HAZARDOUS

Flow through the crack can cause failure of the dam.

SEEPAGE WATER EXITING AS A BOIL IN THE FOUNDATION

Some part of the foundation material is supplying a flow path. This could be caused by a sand or gravel layer in the foundation.

HAZARDOUS

Increased flows can lead to erosion of the foundation and failure of the dam.

1. Examine the boil for transportation of foundation materials.
2. If soil particles are moving downstream, sandbags or earth should be used to create a dike around the boil. The pressure created by the water level within the dike may control flow velocities and temporarily prevent further erosion.
3. If erosion is becoming greater, the reservoir level should be lowered.
4. A qualified engineer should inspect the condition and recommend further actions to be taken.

ENGINEER REQUIRED
**PROBLEM**

**SEEPAGE EXITING AT ABUTMENT CONTACT**

PROBABLE CAUSE
1. Water flowing through pathways in the embankment.
2. Water flowing through the embankment.

POSSIBLE CONSEQUENCES
HAZARDOUS
Can lead to erosion of embankment materials and failure of the dam.

RECOMMENDED ACTIONS
1. Study leakage areas to determine quantity of flow and assess rate of saturation.
2. Inspect daily for developing slides.
3. Water level in reservoir may need to be lowered to assure safety of the embankment.
4. A qualified engineer should inspect the condition and recommend further actions to be taken.

ENGINEER REQUIRED

**LARGE AREA WET OR PRODUCING FLOW**

A seepage path has developed through the embankment or embankment materials and failure of the dam can occur.

HAZARDOUS
1. Increased flows could lead to erosion of embankment material and failure of the dam.
2. Saturation of the embankment can lead to local slides which could cause failure of the dam.

RECOMMENDED ACTIONS
1. Stake out the saturated area and monitor for growth of shrinking.
2. Measure any outflows as accurately as possible.
3. Reservoir level may need to be lowered if saturated areas increase in size at a fixed storage level or if flow increases.
4. A qualified engineer should inspect the condition and recommend further actions to be taken.

ENGINEER REQUIRED

**MARKED CHANGE IN VEGETATION**

1. Embankment materials are supplying flow paths.
2. Natural seeding by wind.
3. Change in seed type during early post construction seeding.

HAZARDOUS
Can show a saturated area.

RECOMMENDED ACTIONS
1. Use probe and shovel to establish if the materials in this area are wetter than surrounding areas.
2. If areas show wetness, when surrounding areas do not, a qualified engineer should inspect the condition and recommend further actions to be taken.

ENGINEER REQUIRED

**BULGE IN LARGE WET AREA**

Downstream embankment materials have begun to move.

HAZARDOUS
Failure of the embankment result from massive sliding can follow these early movements.

RECOMMENDED ACTIONS
1. Compare embankment cross section to the end of construction condition to see if observed condition may reflect end of construction.
2. Stake out affected area and accurately measure outflow.
3. A qualified engineer should inspect the condition and recommend further actions to be taken.

ENGINEER REQUIRED
**PROBLEM**

**TRAMPOLINE EFFECT IN LARGE SOGGY AREA**

1. Water moving rapidly through the embankment or foundation is being controlled or contained by a well-established turf root system.

**PROBABLE CAUSE**

**POSSIBLE CONSEQUENCES**

**RECOMMENDED ACTIONS**

1. Carefully inspect the area for outflow quantity and any transported material.

2. A qualified engineer should inspect the condition and recommend further actions to be taken.

ENGINEER REQUIRED

---

**LEAKAGE FROM ABUTMENTS BEYOND THE DAM**

Water moving through cracks and fissures in the abutment materials.

**HAZARDOUS**

1. Water moving through cracks and fissures in the abutment materials.

**RECOMMENDED ACTIONS**

1. Carefully inspect the area to determine quantity of flow and amount of transported material.

2. A qualified engineer or geologist should inspect the condition and recommend further actions to be taken.

ENGINEER REQUIRED

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**WET AREA IN HORIZONTAL BAND**

Frost layer or layer of sandy material in original construction.

**HAZARDOUS**

1. Water moving through cracks and fissures in the abutment materials.

**RECOMMENDED ACTIONS**

1. Determine as closely as possible the flow being produced.

2. If flow increases, reservoir level should be reduced until flow stabilizes or stops.

3. Stake out the exact area involved.

4. Using hand tools, try to identify the material allowing the flow.

1. A qualified engineer should inspect the condition and recommend further actions to be taken.

ENGINEER REQUIRED

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**LARGE INCREASE IN FLOW OR SEDIMENT IN DRAIN OUTFALL**

A shortened seepage path or increased storage levels.

**HAZARDOUS**

1. Higher velocity flows can cause erosion of drain then embankment materials.

2. Can lead to piping failure.

**RECOMMENDED ACTIONS**

1. Accurately measures outflow quantity and determine amount of increase over previous flow.

2. Collect jar samples to compare turbidity.

3. If either quantity or turbidity has increased by 25%, a qualified engineer should evaluate the condition and recommend further actions.

ENGINEER REQUIRED
**Figure 5.4**  
*Inspection Guidelines - Concrete Upstream Slope*

<table>
<thead>
<tr>
<th>PROBLEM</th>
<th>PROBABLE CAUSE</th>
<th>POSSIBLE CONSEQUENCES</th>
<th>RECOMMENDED ACTIONS</th>
</tr>
</thead>
<tbody>
<tr>
<td>CRACKED DETERIORATED CONCRETE FACE</td>
<td>Concrete deteriorated resulting from weathering, joint filler deteriorated or displaced.</td>
<td>Soil is eroded behind the face and cavities can be formed. Unsupported sections of concrete crack. Ice action may displace concrete.</td>
<td>Determine cause. Either patch with grout or contact engineer for permanent repair method.</td>
</tr>
<tr>
<td>CRACKS DUE TO DRYING</td>
<td>The soil loses its moisture and shrinks, causing cracks. NOTE: Usually near crest and downstream slopes mostly.</td>
<td>Heavy rains can fill up cracks and cause small parts of embankment to move along internal slip surface.</td>
<td>1. Monitor cracks for increases in width, depth, or length. 2. A qualified engineer should inspect the condition and recommend further actions to be taken.</td>
</tr>
</tbody>
</table>

**Figure 5.5**  
*Inspection Guidelines - Spillways*

<table>
<thead>
<tr>
<th>EXCESSIVE VEGETATION OR DEBRIS IN CHANNEL</th>
<th>PROBABLE CAUSE</th>
<th>POSSIBLE CONSEQUENCES</th>
<th>RECOMMENDED ACTIONS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Accumulation of slide materials, dead trees, excessive vegetative growth, etc., in spillway channel.</td>
<td>Reduced discharge capacity; overflow of spillway; overtopping of dam. Prolonged overtopping can cause failure of the dam.</td>
<td>Clean out debris periodically; control vegetative growth in spillway channel. Installing boom in front of spillway entrance to intercept debris.</td>
<td></td>
</tr>
</tbody>
</table>
PROBLEM
EROSION CHANNELS

PROBABLE CAUSE
Surface runoff from intense rainstorms or flow from spillway carries surface material down the slope, resulting in continuous troughs. Livestock traffic create gullies where flow concentrates vary.

POSSIBLE CONSEQUENCES
Unabated erosion can lead to slides, slumps or slips which can result in reduced spillway capacity. Inadequate spillway capacity can lead to embankment overtopping and result in dam failure.

RECOMMENDED ACTIONS
Photograph condition. Repair damaged areas by replacing eroded material with compacted fill. Protect areas against future erosion by using suitable rock riprap. Revegetate area if appropriate. Bring condition to the attention of the engineer during next inspection.

EXCESSIVE EROSION IN EARTH-SLIDE CAUSES CONCENTRATED FLOWS

PROBABLE CAUSE
Discharge velocity too high; bottom and slope material loose or deteriorated; channel and bank slopes too steep; bare and unprotected; poor construction protective surface failed.

POSSIBLE CONSEQUENCES
Disturbed flow pattern; loss of material; increased sediment load downstream; collapse of banks; failure of spillway; can lead to rapid evacuation of the reservoir through the severely eroded spillway.

RECOMMENDED ACTIONS

END OF SPILLWAY CHUTE UNDERCUT

PROBABLE CAUSE
Poor configuration of tailing basin area. Highly erodible material. Absence of cutoff wall at end of chute.

POSSIBLE CONSEQUENCES
Structural damage to spillway structure, collapse of slab and wall lead to costly repair.

RECOMMENDED ACTIONS
Dewater affected area; clean out eroded area and properly backfill. Improve stream channel below chute; provide properly sized riprap in tailing basin area. Install cutoff wall.

WALL DISPLACEMENT

PROBABLE CAUSE
Poor workmanship; uneven settlement of foundation; excessive earth and water pressure; insufficient steel bar reinforcement of concrete.

POSSIBLE CONSEQUENCES
Minor displacement will create eddies and turbulence in the flow, causing erosion of the soil behind the wall. Major displacement will cause severe cracks and eventual failure of the structure.

RECOMMENDED ACTIONS
Reconstruction should be done according to sound engineering practice. Foundation should be carefully prepared. Adequate weep holes should be installed to relieve water pressure behind wall. Use enough reinforcement in the concrete. Anchor walls in prevent further displacement. Install grout between spillway walls if needed. Clean out and backflush drains to assure proper operation. Consult an engineer before action is taken.

ENGINEER REQUIRED
PROBLEM

LARGE CRACKS

PROBABLE CAUSE
Construction defect; local concentrated stress; local material deterioration; foundation failure; excessive backfill pressure.

POSSIBLE CONSEQUENCES
HAZARDOUS
Disturbance in flow patterns; erosion of foundation and backfill; eventual collapse of structure.

RECOMMENDED ACTIONS
Large cracks without large displacement should be repaired by patching. Surrounding areas should be cleaned or cut out before patching material is applied. (See Chapter 7.) Installation of weep holes or other actions may be needed.

OPEN OR DISPLACED JOINTS

PROBABLE CAUSE
Excessive and uneven settlement of foundation; sliding of concrete slab; construction joints too wide and left unsealed. Sealant deteriorated and washed away.

POSSIBLE CONSEQUENCES
HAZARDOUS
Erosion of foundation material may weaken support and cause further cracks; pressure induced by water flowing over displaced joints may wash away wall or slab, or cause excessive undermining.

RECOMMENDED ACTIONS
Construction joint should be no wider than 1/2 inch. All joints should be sealed with asphalt or other flexible materials. Water slopes should be used where feasible. Clean the joint, replace eroded materials, and seal the joint. Foundations should be properly drained and prepared. Underside of chase slabs should have ribs of enough depth to prevent sliding. Avoid steep chutes slopes.

ENGINEER REQUIRED

BREAKDOWN AND LOSS
OF RIPRAP

PROBABLE CAUSE
Slope too steep; material poorly graded; failure of subgrade; flow velocity too high; improper placement of material; bedding material or foundation washed away.

POSSIBLE CONSEQUENCES
HAZARDOUS
Erosion of channel bottom and banks; failure of spillway.

RECOMMENDED ACTIONS
Design a stable slope for channel bottom and banks. Riprap material should be well graded (the material should contain small, medium, and large particles). Sub-grade should be properly prepared before placement of riprap. Install filter fabric if necessary. Control flow velocity in the spillway by proper design. Riprap should be placed according to specifications. Services of an engineer are recommended.

ENGINEER REQUIRED

MATERIAL DETERIORATION-SPALLING
AND DISINTEGRATION OF RIPRAP,
CONCRETE, ETC.

PROBABLE CAUSE
Use of unsound or defective materials; structures subject to freeze-thaw cycles; improper maintenance practices; harmful chemicals.

POSSIBLE CONSEQUENCES
Structure life will be shortened; premature failure.

RECOMMENDED ACTIONS
Avoid using shale or sandstone for riprap. Add air entraining agent when mixing concrete. Use only clean good quality aggregates in the concrete. Steel bars should have at least 1 inch of concrete cover. Concrete should be kept wet and protected from freezing during curing. Timber should be treated before using.
<table>
<thead>
<tr>
<th>PROBLEM</th>
<th>PROBABLE CAUSE</th>
<th>POSSIBLE CONSEQUENCES</th>
<th>RECOMMENDED ACTIONS</th>
</tr>
</thead>
<tbody>
<tr>
<td>POOR SURFACE DRAINAGE</td>
<td>No weep holes; no drainage facility; plugged drains.</td>
<td>Wet foundation, has lower supporting capacity; uplift pressure resulting from seepage water may cause damage to spillway chute; accumulation of water may also increase total pressure on spillway walls and cause damage.</td>
<td>Install weep holes on spillway walls. Inner end of hole should be reinforced and packed with graded filtering material. Install drain system under spillway near downstream end. Clean out existing weep holes. Backflush and rehabilitate drain system under the supervision of an engineer. ENGINEER REQUIRED</td>
</tr>
<tr>
<td>CONCRETE EROSION, ABRASION, AND FRACTURING</td>
<td>Flow velocity too high (usually occurs at lower end of chute in high dams); rolling of gravel and rocks down the chute; cavity behind or below concrete slab.</td>
<td>Rock marks and spalling of concrete surface may progressively become worse; small hole may cause undermining of foundation, leading to failure of structure.</td>
<td>Remove rocks and gravels from spillway chute before flood season. Raise water level in spillway basin. Use good quality concrete. Ensure concrete surface is smooth. ENGINEER REQUIRED</td>
</tr>
<tr>
<td>LEAKAGE IN OR AROUND SPILLWAY</td>
<td>1. Cracks and joints in geologic formation at spillway are permitting seepage.</td>
<td>1. Could lead to excessive loss of stored water. 2. Could lead to progressive failure if velocities are high enough to cause erosion of natural materials.</td>
<td>HAZARDOUS 1. Could lead to excessive loss of stored water. 2. Measure flow quantity and check for erosion of natural materials. 3. If flow rate or amount of eroded material increases rapidly, reservoir level should be lowered until flow stabilized on stored. 4. A qualified engineer should inspect the condition and recommend further actions to be taken. ENGINEER REQUIRED</td>
</tr>
<tr>
<td>TOO MUCH LEAKAGE FROM SPILLWAY UNDER DRAINS</td>
<td>Drain or cutoff may have failed.</td>
<td>HAZARDOUS 1. Excessive flows under the spillway could lead to erosion of foundation material and collapse of parts of the spillway. 2. Uncontrolled flows could lead to loss of stored water.</td>
<td>Same as above.</td>
</tr>
</tbody>
</table>
**Problem**

**Seepage from a construction joint or crack in concrete structure**

**Probable Cause**

Water is collecting behind structure because of insufficient drainage or clogged weep holes.

**Possible Consequences**

1. Can cause walls to dip in and over. Flows through concrete can lead to rapid deterioration from weathering.
2. If the spillway is located within the embankment, rapid erosion can lead to failure of the dam.

**Recommended Actions**

1. Check area behind wall for pooling of surface water.
2. Check and clean sumps, drain outlets, flush lines, and weep holes.
3. If conditions permit, a qualified engineer should inspect the condition and recommend further action to be taken.

**Figures 5.6**

**Inspection Guidelines - Inlets, Outlets and Drains**

**Outlet Pipe Damage**

**Crack**

- Settlement impact.
- Rust (steel pipe)
- Erosion (concrete pipe)
- Cavitation

**Hole**

- Excessive seepage, possible internal erosion.
- Hazardous

**Joint Offset**

- D & HAZARDOUS
- Provided passageway for water to exit or enter pipe, resulting in erosion of internal material of the stem.

**Control Works**

**1. Broken Support Block**

Concrete deterioration. Excessive force exerted on control stem by trying to open gate when it was jammed.

**2. Bent/Broken Control Stem**

Rust. Excessive force used to open or close gate. Inadequate or broken stem guides.

**3. Broken/Missing Stem Guides**

Rust. Inadequate lubrication. Excessive force used to open or close gate when it was jammed.

**HAZARDOUS**

Outlet is inoperable.

**HAZARDOUS**

Provided passageway for water to exit or enter pipe, resulting in erosion of internal material of the stem.

Any of these conditions can mean the control is either inoperable or at best partly operable. Use of the system should be minimized or discontinued. If the outlet system has a second control valve, consider using it to regulate release until repairs can be made. Engineering help is recommended.
<table>
<thead>
<tr>
<th>PROBLEM</th>
<th>PROBABLE CAUSE</th>
<th>POSSIBLE CONSEQUENCES</th>
<th>RECOMMENDED ACTIONS</th>
</tr>
</thead>
<tbody>
<tr>
<td>FAILURE OF CONCRETE OUTFALL STRUCTURE</td>
<td>Excessive side pressures on nonreinforced concrete structure. Poor concrete quality.</td>
<td>HAZARDOUS</td>
<td>1. Check for progressive failure by monitoring structural dimensions, such as &quot;D&quot; shown in figure.</td>
</tr>
<tr>
<td></td>
<td>Outlet pipe too short. Lack of energy dissipating pool or structure at downstream end of conduit.</td>
<td></td>
<td>2. Repair cracks and apply drainage around concrete structure. Total replacement of outlet structure may be needed.</td>
</tr>
<tr>
<td>OUTLET RELEASES ERODING TOE OF DAM</td>
<td></td>
<td>HAZARDOUS</td>
<td>1. Extend pipe beyond toe (use a pipe of same size and material, and form watertight connection to existing conduit).</td>
</tr>
<tr>
<td>VALVE LEAKAGE</td>
<td>Trashback missing or damaged.</td>
<td></td>
<td>2. Protect embankment with riprap over suitable bedding.</td>
</tr>
<tr>
<td>DEBRIS STUCK UNDER GATE</td>
<td>Ice action, rust, affect vibration, or stress resulting from forcing gate closed when it is jammed.</td>
<td>Gate will not close. Gate or stem may be damaged in effort to close gate.</td>
<td>Raises and lowers gate slowly until debris is hoisted and flows past valve. When reservoir is lowered, repair or replace trashback.</td>
</tr>
<tr>
<td>CRACKED GATE LEAF</td>
<td>Rust, erosion, cavitation, vibration, or wear.</td>
<td>Gate-leaf main failure complete, evacuating reservoir.</td>
<td>Use valve only in fully open or closed position. Minimize use of valve until leaf can be repaired or replaced.</td>
</tr>
<tr>
<td>DAMAGE GATE SEAT OR GUIDES</td>
<td></td>
<td>Leakage and loss of support for gate leaf. Gate may bind in guides and become inoperable.</td>
<td>Minimize use of valve until guide/seat can be repaired. If cavitation is the cause, check to see if air vent pipe exists and is unobstructed.</td>
</tr>
<tr>
<td>SEEPAGE WATER EXITING FROM A POINT ADJACENT TO THE OUTLET</td>
<td>1. A break in the outlet pipe. 2. A path for flow has developed along the outside of the outlet pipe.</td>
<td>HAZARDOUS</td>
<td>1. Thoroughly investigate the area by probing and/or shovel-pitting to see if the cause can be determined.</td>
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<td>Continued flows can lead to rapid erosion of embankment materials and failures of the</td>
<td>2. Determine if leakage is carrying soil particles.</td>
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<td>3. Determine quantity of flow.</td>
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<td>4. If flow increases, or if carrying embankment materials, reservoir level should be lowered until leakage stops.</td>
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<td>5. A qualified engineer should inspect the condition and recommend further actions to be taken.</td>
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Table 6.1 lists features to be observed at a dam and the suggested instruments or observation technique to be used. The specific sections of this manual where an instrument or observation technique is discussed are also indicated.

### Table 6.1

**INSTRUMENTATION AND MONITORING GUIDELINES DIRECTORY**

<table>
<thead>
<tr>
<th>MEANS OF PROBLEM DETECTION</th>
<th>VISUAL OBSERVATION (6.3.1)</th>
<th>MOVEMENTS (6.3.2)</th>
<th>UPLIFIT &amp; PORE PRESSURE (6.3.3)</th>
<th>WATER LEVELS &amp; FLOW (6.3.4)</th>
<th>SEEPAGE FLows (6.3.5)</th>
<th>WATER QUALITY (6.3.6)</th>
<th>TEMP. MEAS. (6.3.7)</th>
<th>CRACK &amp; JOINT MEAS.</th>
<th>SEISMIC MEAS. (6.3.9)</th>
<th>STRESS-STRAIN MEAS. (6.3.10)</th>
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