CHAPTER 6
INSTRUMENTATION AND MONITORING
GUIDELINES

6.0 GENERAL

"Instrumentation of a dam furnishes data to determine if the completed structure is functioning as intended and to provide a continuing surveillance of the structure to warn of any developments which endanger its safety" (ICOLD, 1969).

The means and methods available to monitor phenomena that can lead to dam failure include a wide spectrum of instruments and procedures ranging from very simple to very complex. Any program of dam safety instrumentation must be properly designed and 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.

Instruments 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 of the dam.

An instrumentation program should involve instruments and evaluation methods that are as simple and straightforward as the project will allow. Beyond that, the dam owner should make a definite commitment to an ongoing monitoring program or the installation of instruments probably will be wasted.

This chapter discusses deficiencies in dams that may be discovered and the types of instruments that may be used to monitor those deficiencies. Table 6.1 describes deficiencies, their causes and generic means for detecting them. Increased knowledge of these deficiencies acquired through a monitoring program is useful in determining both the cause of the deficiency and the necessary remedy.

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.

6.1 REASONS FOR INSTRUMENTATION

Instrumentation and proper monitoring and evaluation are extremely valuable in determining the performance of a dam. Specific reasons for instrumentation include:

- Warning of a Problem - Often, instruments can detect unusual changes, such as water fluctuations in pressure that are not visible. In other cases, gradual progressive changes in say seepage flow, which would go unnoticed visually, can be monitored regularly. This monitoring can warn of the development of a serious seepage problem.

- Analyzing and Defining a Problem - Instrumentation data is frequently used to provide engineering information necessary for analyzing and defining the extent of a problem. For example, downstream movement of a dam because of high reservoir water pressure must be analyzed to determine if the movement is uniformly distributed along the dam, whether the movement is in the dam, the foundation, or both, and whether the movement is continuing at a constant, increasing or decreasing rate. Such information can then be used to design corrective measures.

- Proving Behavior Is as Expected - Instruments installed at a dam may infrequently (or even never) show any anomaly or problem. However, even this information is valuable because it shows that the dam is performing as designed and provides peace of mind to an owner. Also, although a problem may appear to be happening or imminent, instrument readings might show that the deficiency
(say increased seepage) is normal (merely a result of higher than normal reservoir level) and was foreseen in the dam's design.

- Evaluating Remedial Action Performance - Many dams, particularly older dams, are modified to allow for increased capacity or to correct a deficiency. Instrument readings before and after the change allow analysis and evaluation of the performance of the modification.

6.2 INSTRUMENT TYPES AND USAGE

A wide variety of devices and procedures are used to monitor dams. The features of dams and dam sites most often monitored by instruments include:

- Movements: (horizontal, vertical, rotational and lateral)
- Pore pressure and uplift pressures
- Water level and flow
- Seepage flow
- Water quality
- Temperature
- Crack and joint size
- Seismic activity
- Weather and precipitation
- Stress and strain

A listing of manufacturers and suppliers for the various instrumentation devices is provided in a report by Dunncliff (1981). Details of the installation, operation, and maintenance of each device are described in U.S. Bureau of Reclamation (1986).

6.2.1 Visual observations - As discussed in Chapter 5, visual observations by the dam owner or the owner's representative may be the most important and effective means of monitoring the performance of a dam. The visual inspections should be made whenever the inspector visits the dam site and should consist of a minimum of walking along the dam alignment and looking for any signs of distress or unusual conditions at the dam.

6.2.2 Movements - Movements occur in every dam. They are caused by stresses induced by reservoir water pressure, unstable slopes (low shearing strength), low foundation shearing strength, settlement (compressibility of foundation and dam materials), thrust due to arching action, expansion resulting from temperature change, and heave resulting from hydrostatic uplift pressures. They can be categorized by direction:

- Horizontal Movement - Horizontal or translational movement commonly happens in an upstream-downstream direction in both embankment and concrete dams. It involves, the movement of an entire dam mass relative to its

Figure 6.1a - Installation of Permanent Points

Figure 6.1b - Plan of Alignment System
abutments or foundation. In an embankment dam, instruments commonly used for monitoring such movement include:
- Extensometers
- Multi-point extensometers
- Inclinometers
- Embankment measuring points
- Shear strips
- Structural measuring points

Installation of simple measuring points is illustrated in Figure 6.1, and a simple crack monitoring system is shown in Figure 6.2, and inclinometer systems and plots are shown in Figure 6.3a-c.

For a concrete dam, instruments for monitoring horizontal movements may include:
- Crack measuring devices
- Extensometers
- Multi-point extensometers
- Inclinometers
- Structural measuring points
- Tape gauges
- Strain meters
- Plumb lines
- Foundation deformation gauges
Examples of monitoring of concrete structure movements are shown in Figure 6.4.

• **Vertical Movement** - Vertical movement is commonly a result of consolidation of embankment or foundation materials resulting in settlement of the dam. Another cause is heave (particularly at the toe of a dam) caused by hydrostatic uplift pressures.

In an embankment dam, vertical movements may be monitored by:
- Settlement plates/sensors
- Extensometers
- Piezometers
- Vertical internal movement devices
- Embankment measuring points
- Structural measuring points
- Inclinometer casing measurements

In a concrete dam, vertical movement monitoring devices may include:
- Settlement sensors
- Extensometers
- Piezometers
- Structural measuring points
- Foundation deformation gauges

• **Rotational Movement** - Rotational movement is commonly a result of high reservoir water pressure in combination with low shearing strength in an embankment or foundation and may occur in either component of a dam. This kind of movement may be measured in either embankment or concrete dams by instruments such as:
- Extensometers
- Inclinometers
- Tiltmeters
- Surface measurement points
- Crack measurement devices
- Piezometers
- Foundation deformation gauges
- Plumblines (concrete only)

• **Lateral Movement** - Lateral movement (parallel with the crest of a dam) is common in concrete arch and gravity dams. The structure of an arch dam causes reservoir water pressure to be translated into a horizontal thrust against each abutment. Gravity dams also exhibit some lateral movement because of expansion and contraction due to temperature changes. These movements may be detected by:
- Structural measurement points
- Tiltmeters
- Extensometers
- Crack measurement devices
- Plumblines
- Strainmeters
- Stressmeters
- Inclinometers
- Jointmeters
- Thermometers
- Load cells

6.2.3 Pore pressure and uplift pressure: As discussed in Chapter 2, a certain amount of water seeps through, under, and around the ends of all dams. The water moves through pores in the soil, rock, or concrete as well as through cracks, joints, etc. The pressure of the water as it moves...
acts uniformly in all planes and is termed pore pressure. The upward force (called uplift pressure) has the effect of reducing the effective weight of the downstream portion of a dam and can materially reduce dam stability. Pore pressure in an embankment dam, a dam foundation or abutment, reduces that component's shearing strength. In addition, excess water, if not effectively channeled by drains or filters, can result in progressive internal erosion (piping) and failure. Pore pressures can be monitored with the following equipment.

- Piezometers
  - electrical
  - open well
  - pneumatic
  - hydraulic
  - porous tube
  - slotted pipe
- Pressure meters & gauges
- Load cells

Simple piezometers may be as illustrated in Figure 6.5, while a basic observation well is shown in Figure 6.6.

6.2.4 Water Level and Flow - For most dams, it is important to monitor the water level in the reservoir and the downstream pool regularly to determine the quantity of water in the reservoir and its level relative to the regular outlet works and the emergency spillway. The water level is also used to compute water pressure and pore pressure; the volume of seepage is usually directly related to the reservoir level. It is also important to establish the normal or typical flow through the outlet works for legal purposes. Water levels may be measured by simple elevation gauges - either staff gauges or numbers painted on permanent, fixed structures in the reservoir - or by complex water level sensing devices. Flow quantities are often computed from a knowledge of the dimensions of the outlet works and the depth of flow in the outlet channel or pipe.

6.2.5 Seepage flow - Seepage must be monitored on a regular basis to determine if it is increasing, decreasing, or remaining constant as the reservoir level fluctuates. A flow rate changing relative to a reservoir water level can be an indication of a clogged drain, piping, or internal cracking of the embankment. Seepage may be measured using the following devices and methods:

- Weirs (any shape such as V-notch, rectangular, trapezoidal, etc.)
- Flumes (such as a Parshall flume)
- Pipe methods
- Timed-bucket methods
- Flow meters

Examples of weirs, flumes, and bucket measuring installations are illustrated in Figures 6.7, 6.8, and 6.9.

6.2.6 Water quality - Seepage comes into contact with various minerals in the soil and rock in and around the dam. This can cause two problems: the chemical dissolution of a natural rock such as limestone, or the internal erosion of soil.
Dissolution of minerals can often be detected by comparing chemical analyses of reservoir water and seepage water. Such tests are site specific; for example, in a limestone area, one would look for calcium and carbonates, in a gypsum area, calcium and sulfates. Other tests, such as pH can also sometimes provide useful information on chemical dissolution.

Internal erosion can be detected by comparing turbidity of reservoir water with that of seepage water. A large increase in turbidity indicates erosion.

6.2.7 Temperature - The internal temperature of concrete dams is commonly measured both during and after construction. During construction, the heat of hydration of freshly placed concrete can create high stresses which could result in later cracking. After construction is completed and a dam is in operation, it is not uncommon for very significant temperature differentials to exist depending on the season of the year. For example, during the winter, the upstream face of a dam remains relatively warm because of reservoir water temperature, while the downstream face of the dam is reduced to a cold ambient air temperature. The reverse is true in the summer. Temperature measurements are important both to determine causes of movement due to expansion or contraction and to compute actual movement. Temperature measurements can be made by using any of several different kinds of embedded thermometers or by making simultaneous temperature readings on devices such as stress and strain meters which provide means for indirectly measuring temperature of the mass.

6.2.8 Crack and joint size - A knowledge of the locations and widths of cracks and joints in concrete dams and in concrete spillways and other concrete appurtenances of embankment dams is important because of the potential for seepage through those openings. Even more, it is important to know if the width of such openings is increasing or decreasing. Various crack and joint measuring devices are available, and most allow very accurate measurement. Some use simple tape or dial gauges, while others use complex electronics to gain measurements.
6.2.9 Seismic activity - Seismic measuring devices record the intensity and duration of large-scale earth movements such as earthquakes. Many federal and state dams use these instruments because they are part of the U.S. Geological Survey's network of seismic recording stations. It may or may not be necessary for a private dam to contain any seismic devices depending upon whether it is in an area of significant seismic risk. Seismic instruments can also be used to monitor any blasting conducted near a dam site.

6.2.10 Weather and precipitation - Monitoring the weather at a dam site can provide valuable information about both day-to-day performance and developing problems. A rain gauge, thermometer, and wind gauge can be easily purchased, installed, maintained and monitored at a dam site.

6.2.11 Stress and strain - Measurements to determine stress and/or strain are common in concrete dams and to a lesser extent, in embankment dams. The monitoring devices previously listed for measuring dam movements, crack and joint size and temperature are also appropriate for measuring stress and strain. Monitoring for stress and strain permits very early detection of movement.

6.3 FREQUENCY OF MONITORING

The frequency of instrument readings or making observations at a dam depends on several factors including:

- Relative hazard to life and property that the dam represents
- Height or size of the dam
- Relative quantity of water impounded by the dam
- Relative seismic risk at the site
- Age of the dam
- Frequency and amount of water level fluctuation in the reservoir

In general, as each of the above factors increases, the frequency of monitoring should increase. For example, very frequent (even daily) readings should be taken during the first filling of a reservoir, and more frequent readings should be taken during high water levels and after significant storms and earthquakes. As a rule of thumb, simple visual observations should be made during each visit to the dam and not less than monthly. Daily or weekly readings should be made during the first filling, immediate readings should be taken following a storm or earthquake, and significant seepage, movement, and stress-strain readings should probably be made at least monthly.
<table>
<thead>
<tr>
<th>REQUIRED MAINTENANCE</th>
<th>EARTHWORK MAINT. (7.3.1)</th>
<th>RIPRAP MAINT. &amp; REPAIR (7.3.2)</th>
<th>VEG. MAINT. (7.3.3)</th>
<th>LIVESTOCK DAMAGE REPAIR (7.3.4)</th>
<th>RODENT DAMAGE REPAIR (7.3.5)</th>
<th>TRAFFIC DAMAGE REPAIR (7.3.6)</th>
<th>MECH. MAINT. (7.3.7)</th>
<th>ELECT. MAINT. (7.3.8)</th>
<th>CLEANING (7.3.9)</th>
<th>CONCRETE MAINT. (7.3.10)</th>
<th>METAL COMPONENTS MAINT. (7.3.11)</th>
</tr>
</thead>
<tbody>
<tr>
<td>FEATURE</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EMBANKMENT DAM</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Upstream Slope</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td>X</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Downstream Slope</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Left/Right Abutments</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td>X</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Crest</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Internal Drainage Sys.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Relief Drains</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Riprap &amp; Slope</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td>X</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Protection</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CONCRETE DAMS</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Upstream Slope</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Downstream Slope</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Left/Right Abutments</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td>X</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Crest</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Internal Drainage Sys.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Relief Drains</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Galleries</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sluiceways/Controls</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SPILLWAYS</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Approach Channel</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inlet/outlet structure</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stilling Basin</td>
<td></td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Discharge conduit/Channel</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Control Features</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Erosion Protection</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td>X</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Side Slopes</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>OUTLETS &amp; DRAINS</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inlet/outlet structure</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stilling Basin</td>
<td></td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Discharge Channel</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Trashrack/Debris Control</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Emergency Systems</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GENERAL AREAS</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reservoir Surface</td>
<td></td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Mech/elect. systems</td>
<td></td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Shoreline</td>
<td></td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Upstream Watershed</td>
<td></td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Downstream Channel</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
<td></td>
<td>X</td>
</tr>
</tbody>
</table>
CHAPTER 7
MAINTENANCE GUIDELINES

7.0 GENERAL
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. Moreover, the cost of a proper maintenance program is small compared to the cost of major repairs, loss of life and property and resultant litigation.

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 at least monthly and after major flood or earthquake events. During each inspection, a checklist of items calling for maintenance should be used.

7.1 MAINTENANCE PRIORITIES
Maintenance is a task which should never be neglected. If it is, several areas ultimately will need attention—some of greater concern than others. The following outline lists, by relative priority, the various problems or conditions that might be encountered in a deteriorated dam

7.1.1 Immediate maintenance - The following conditions are critical and call for immediate attention:

- A dam about to be overtopped or being overtopped
- A dam about to be breached (by progressive erosion, slope failure, or other circumstances)
- A dam showing signs of piping or internal erosion indicated by increasingly cloudy seepage or other symptoms
- A spillway being blocked or otherwise rendered inoperable, or having normal discharge restricted

- Evidence of excessive seepage appearing anywhere at the dam site (an embankment becoming saturated, seepage exiting on the downstream face of a dam) increasing in volume.

Although the remedy for some critical problems may be obvious (such as clearing a blocked spillway), the problems listed above generally require the services of a Professional Engineer familiar with the construction and maintenance of dams. The emergency action plan (discussed in Chapter 8) should be activated when any of the above conditions are noted.

7.1.2 Required maintenance at earliest possible date - The following maintenance should be completed as soon as possible after the defective condition is noted:

- All underbrush and trees should be removed from the dam, and a good grass cover should be established
- Eroded areas and gullies on embankment dams should be restored and reseeded
- Defective spillways, gates, valves, and other appurtenant features of a dam should be repaired
- Deteriorated concrete or metal components of a dam should be repaired as soon as weather permits

7.1.3 Continuing maintenance - Several tasks should be performed on a continuing basis:

- Routine mowing and general maintenance
- Maintenance and filling of any cracks and joints on concrete dams
- Observation of any springs or areas of seepage
- Inspection of the dam (as discussed in Chapter 5)
- Monitoring of development in the watershed which would materially increase runoff from storms
Monitoring of development downstream and updating the emergency notification plan to include new homes or other occupied structures within the area.

7.2 SPECIFIC MAINTENANCE ITEMS

7.2.1 Earthwork Maintenance and Repair - Deterioration of the surfaces of an earth dam may occur for several reasons. For example, wave action may cut into the upstream slope, vehicles may cause ruts in the crest or slopes, or runoff waters may leave erosion gullies on the downstream slope. Other special problems, such as shrinkage cracks or root damage, may also occur. Damage of this nature must be repaired on a continuing basis. The maintenance procedures described below are effective in repairing minor earthwork problems. However, this section is not intended to be a technical guide, and the methods discussed should not be used to solve serious problems. Conditions such as embankment slides, structural cracking, and sinkholes threaten the immediate safety of a dam and require immediate repair under the direction of an engineer.

The material selected for repairing embankments depends upon the purpose of the earthwork. Generally, earth should be free from vegetation, organic materials, trash, or large rock. Most of the earth should be fine-grained soils or earth clods which easily break down when worked with compaction equipment. The intent is to use a material which, when compacted, forms a firm, solid mass, free from excessive voids.

If flow-resistant portions of an embankment are being repaired, materials which are high in clay or silt content should be used. If the area is to be free draining or highly permeable (i.e., riprap bedding, etc.) the material should have a higher percentage of sand and gravel. As a general rule, it is usually satisfactory to replace or repair damaged areas with soils similar to those originally in place.

An important soil property affecting compaction is moisture content. Soils which are too dry or too wet do not compact well. One may roughly test repair material by squeezing it into a tight ball. If the sample maintains its shape without cracking and falling apart (which means it is too dry), and without depositing excess water onto the hand (which means it is too wet), the moisture content is probably near the proper level.

Before placement of earth, the repair area must be prepared by removing all inappropriate material. Vegetation such as brush, roots, and tree stumps must be cleared and any large rocks or trash removed. Also, unsuitable earth, such as organic or loose soils, should be removed, so that the work surface consists of exposed firm clean embankment material.

Following clean-up, the affected area should be shaped and dressed, so that the new fill can be compacted and will properly tie into the existing fill. If possible, slopes should be trimmed, and surfaces roughened by scarifying or plowing to improve the bond between the new and existing fill and to provide a good base to compact against.

Soils should be placed in loose layers up to 8 inches thick and compacted manually or mechanically to form a dense mass free from large rock or organic material. Soil moisture must be maintained in the proper range. The fill should be watered and mixed to the proper wetness or scarified and allowed to dry if too wet.

During backfilling, care should be taken that fill does not become too wet from rainstorm runoff. Runoff should be directed away from the work area and repair areas should be overfilled so that the fill maintains a crown which will shed water.

As mentioned earlier, occasionally minor cracks will form in an earth dam because of surface drying. These are called desiccation (drying) cracks and should not be confused with structural or settlement cracks. Drying cracks are usually parallel to the main axis of the dam, typically near the upstream or downstream shoulders of the crest. These cracks often run intermittently along the length of the dam and may be up to 4 feet deep. Drying cracks can be distinguished from more serious structural cracks because the former are usually no wider than a few inches and have edges that are not offset vertically.

As a precaution, suspected drying cracks should initially be monitored with the same care used for structural cracks. The problem area should be marked with survey stakes, and monitoring pins should be installed on either side of the crack to allow recording of any changes in width or vertical offset. Once satisfied that observed cracking is the result of shrinkage or drying, an owner may stop monitoring.

However, these cracks will close as climatic or soil moisture conditions change. If they do not, it may be necessary to backfill the cracks to prevent entry of surface moisture which could result in saturation of the dam. The cracks may be simply filled with earth that is tampèd in place with hand or tools. It is also recommended that the crest of a dam be graded to direct runoff waters away from areas damaged by drying cracks.

As Chapter 5 suggests, erosion is one of the most common maintenance problems at embankment structures. Erosion is a natural process, and its continuous forces will eventually wear down almost any surface or structure. Periodic and timely maintenance is essential to prevent continuous deterioration and possible failure.

Sturdy sod, free from weeds and brush, is an effective means of preventing erosion. Embankment slopes are normally designed and constructed so that surface drainage will be spread out in thin layers (sheet flow) on the grassy cover. When embankment sod is in poor condition or flows are concentrated at any location, the resulting erosion will leave rills and gullies in the embankment slope. An owner should look for such areas and be aware of the problems that may develop. Eroded areas must be promptly repaired to prevent more serious damage to the embankment. Rills and gullies should be filled with suitable soil (the upper 4 inches should be top soil, if possible,) compacted, and then seeded. A local Soil Conservation Service Office can be very helpful in selecting the types of grass to use for dam surface protection. Erosion in large gullies can be slowed by stacking bales of hay or straw across the gully until permanent repairs can be made.

Not only should eroded areas be repaired, but the cause of the erosion should be found to prevent a continuing maintenance problem. Erosion
might be caused or aggravated by improper drainage, settlement, pedestrian traffic, animal burrows, or other factors. The cause of the erosion will have a direct bearing on the type of repair needed.

Paths due to pedestrian or two-wheel and four-wheel vehicle traffic are a problem on many embankments. If a path has become established, vegetation will not provide adequate protection and more durable cover will be required unless traffic is eliminated. Small stones, asphalt, or concrete may be used effectively to cover footpaths. In addition, railroad ties or other treated wood beams can be embedded into an embankment slope to form an inexpensive stairway.

Erosion is also common at the point where an embankment and the concrete walls of a spillway or other structure meet. Poor compaction adjacent to such a wall during construction and subsequent settlement can result in an area along the wall lower than the grade of the embankment. Runoff, therefore, often concentrates along these structures, resulting in erosion. People also frequently walk along these walls, wearing down the vegetal cover. Possible solutions include regrading the area so that it slopes away from the wall, adding more resistant surface protection, or constructing wooden steps.

Adequate erosion protection is also needed along the contact between the downstream face of an embankment and the abutments. Runoff from rainfall can concentrate in gutters constructed in these areas and can reach erosive velocities because of relatively steep slopes. Berms on the downstream face that collect surface water and empty into these gutters add to the runoff volume. Sod-surfaced gutters may not adequately prevent erosion in these areas. Paved concrete gutters may not be desirable either because they do not slow the water and can be undermined by erosion. Also, small animals often construct burrows underneath these gutters adding to the erosion potential.

A well-graded mixture of rocks up to 9 to 12 inches in diameter (or larger) placed on a layer of sand (filter) generally provides the best protection for these gutters on small dams. Riprap slushed with a thin concrete slurry has also been successful in preventing erosion on larger dams and should be used if large stone material is not available.

As with erosion around spillways, erosion adjacent to gutters results from improper construction or a poor design in which the finished gutter is too high with respect to adjacent ground. This condition prevents much of the runoff water from entering the gutter. Instead, the flow concentrates along the side of the gutter, erodes and may eventually undermine the gutter.

Care should be taken when replacing failed gutters or designing new gutters to assure that:

- The channel has adequate capacity
- Adequate erosion protection and a satisfactory filter have been provided
- Surface runoff can easily enter the gutter
- The outlet is adequately protected from erosion

7.2.2 Riprap maintenance and repair - A serious erosion problem called "beaching" can develop on the upstream slope of a dam. Waves caused by high winds or high-speed boats can erode the exposed face of an embankment by repeatedly striking the surface just above the pool elevation, rushing up the slope, then tumbling back into the pool. This action erodes material from the face of the embankment and displaces it down the slope, creating a "beach." Erosion of unprotected soil can be rapid and, during a severe storm, could lead to complete failure of a dam.

The upstream face of a dam is commonly protected against wave erosion and resultant beaching by placement on the face of a layer of rock riprap over a layer of filter material. Sometimes, materials such as steel, bituminous or concrete facing, bricks or concrete blocks are used for this upstream slope protection. Protective beaches are sometimes actually built into small dams by placing a berm (8 to 10 feet wide) along the upstream face a short distance below the normal pool level thereby providing a surface on which wave energy can dissipate. Generally, however, rock riprap provides the most economical and effective protection.

Nonetheless, beaching can occur in existing riprap if the embankment surface is not properly protected by a filter. Water running down the slope under the riprap can erode the embankment. Sections of riprap which have slumped downward are often signs of this kind of beaching. Similarly, concrete facing used to protect slopes may fail because waves wash soil from beneath the slabs through joints and cracks. Detection of this problem is difficult because the voids are hidden and failure may be sudden and extensive. Effective slope protection must prevent soil from being removed from the embankment.

When erosion occurs and beaching develops on the upstream slope of a dam, repairs should be made as soon as possible. The pool level should be lowered and the surface of the dam prepared for repair. A small berm or "bench" should be built across the face of the dam at the base of the new layer of protection to help hold the new layer in place. The size of the bench needed depends on the thickness of the protective layer.

A riprap layer should extend a minimum of 3 feet below the lowest expected normal pool level. Otherwise, wave action during periods of low lake level will undermine and destroy the protection.

If rock riprap is used, it should consist of a heterogeneous mixture of irregular shaped stone placed over a sand and gravel filter. The largest rock must be large enough in both size and weight to break up the energy of the maximum expected waves and hold smaller stones in place. (An engineer may have to be consulted to determine size.) The smaller rocks help to fill the spaces between the larger pieces and to form a stable mass. The filter prevents soil particles on the embankment surface from being washed out through the spaces between the rocks in the riprap. If the filter material itself can be washed out through these voids and beaching develops, two layers of filters may be required. The lower layer should be composed of sand or filter fabric to protect the soil surface and the upper layer should be composed of coarser materials.

A dam owner should expect some riprap deterioration because of weathering. Freezing and thawing, wetting and drying, abrasive wave action and other natural processes will eventually break down the material. Therefore, sufficient maintenance funds should be allocated for the regular replacement of riprap.
The useful life of riprap varies depending on the characteristics of the stone used. Thus, stone for riprap should be rock that is dense and well cemented. When riprap breaks down, and erosion and beaching occur more often than once every three to five years, professional advice should be sought to design more effective slope protection.

7.2.3 Vegetation maintenance - The entire dam should be kept clear of unwanted vegetation such as brush or trees. Excessive growth may cause several problems:
- It can obscure the surface of an embankment and prevent a thorough inspection of the dam
- Large trees can be uprooted by high wind or erosion and leave large holes, that can lead to breaching of the dam
- Some root systems can decay and rot, providing passageways for water, and thus causing erosion
- Growing root systems can lift concrete slabs or structures
- Weeds can prevent the growth of desirable grasses
- Rodent habitats can develop

When brush is cut down, it should be removed from a dam to permit a clear view of the embankment. Following removal of large brush or trees, the left over root systems should also be removed if possible and the resulting holes properly filled. In cases where they cannot be removed, root systems can be treated with herbicide (properly applied) to retard further growth. After the removal of brush, cuttings may need to be burned. If this is done, dam owners should notify the local fire department, forest service, or other agency responsible for fire control.

If properly maintained, grass is not only an effective means of controlling erosion, it also enhances the appearance of a dam and provides a surface that can be easily inspected. Grass roots and stems tend to trap fine sand and soil particles, forming an erosion-resistant layer once the plants are well established. Grass is least effective in areas of concentrated runoff or in areas subjected to wave action.

7.2.4 Livestock control - Livestock should not be allowed to graze on an embankment surface. When soil is wet, they can damage vegetation and destroy the uniformity of the surface. Moreover, livestock tend to walk in established paths and thus can promote severe erosion. Such paths should be regraded and seeded, and the livestock should be permanently fenced out of the area.

7.2.5 Rodent damage control - Rodents, such as groundhogs (woodchucks), muskrats, and beavers are naturally attracted to the habitats created by dams and reservoirs and can, by their behavior, endanger the structural integrity and proper performance of embankments and spillways. Groundhog and muskrat burrows can weaken embankments and can serve as pathways for seepage. Beavers can plug a spillway and raise the pool level. Rodent control is essential to the preservation of a dam.

The groundhog is the largest member of the squirrel family. Its coarse fur is a typically grayish brown with a reddish cast. Occupied groundhog burrows are easily recognized in the spring because of the groundhog's habit of keeping them "cleaned out." Fresh soil is generally found at the mouth of such active burrows. Half-round mounds, paths leading from the den to nearby fields, and clawed or girdled trees and shrubs also indicate inhabited burrows and dens.

When burrowing into an embankment, groundhogs stay above the phreatic surface (upper surface of seepage or saturation) to stay dry. The burrow is rarely a single tunnel. It is usually forked, with more than one entrance and with several side passages or rooms from 1 to 12 feet in length.

Controls should be implemented during early spring when active burrows are easy to find, young groundhogs have not yet scattered, and there is less likelihood of damage to other wildlife. In summer, fall, and winter, ground animals may scurry into groundhog burrows for brief protection and may even take up permanent residence during the period of groundhog hibernation.

Groundhogs can be controlled with fumigants or firearms. Fumigation is the most practical method although around buildings or high fire hazard areas, shooting may be preferable. Gas cartridges for fumigation may be purchased at local farm exchanges, farm supply centers, and many county extension offices.

Groundhogs will be discouraged from inhabiting an embankment if the grass cover is kept mowed.

The muskrat is a stocky rodent with a broad head, short legs, small eyes, and rich dark brown fur. Muskrats are chiefly nocturnal and can be found wherever there are marshes, swamps, ponds, lakes, and streams having calm or very slowly moving water with vegetation in the water and along the banks.

Barriers, such as properly constructed riprap and filter layers, provide the most practical protection from muskrats by preventing burrowing. As a muskrat tries to construct a burrow, the sand and gravel of a filter layer will cave in and discourage den building. Filter layers and riprap should extend at least 3 feet below water line. Heavy wire fencing laid flat against a slope and extending above and below the waterline can also be effective. Eliminating or reducing aquatic vegetation along a shoreline will also discourage muskrat habitation. Trapping with steel traps is normally the most practical method of removing muskrats that have already inhabited a pond.

The easily recognized beaver, if inhabiting an area around a dam, will try to plug the spillway with their cuttings. Routinely removing the cuttings can alleviate the problem or an electrically charged wire or wires can be placed around the spillway inlet. Beaver may be trapped during the proper season and sometimes a local fur trapper will perform the work at little or no expense to the owner.

Methods of repairing rodent damage depend upon the nature of the damage, but in any case, extermination of the rodent population is the required first step. If the damage consists mostly of shallow holes scattered across an embankment, repair may be necessary to maintain the appearance of the dam, to keep runoff waters from infiltrating the dam, or to discourage rodents from subsequently returning to the embankment. In these cases, tamping of earth into the rodent hole should be sufficient repair. Soil should be placed as deeply as possible and compacted with a pole or shovel handle.

Large burrows on an embankment should be filled by mud-packing. This simple, inexpensive method involves placing one or two lengths of metal stove or vent pipe vertically over the entrance of the den with a tight seal.
between the pipe and den. A mud-pack mixture is then poured into the pipe until the burrow and pipe are filled with the earth-water mixture. The pipe is removed and additional dry earth is tamped into the entrance. The mud-pack mixture is made by adding water to a 90 percent earth and 10 percent cement mixture until a slurry of thin cement is attained. All entrances should be plugged with well-compacted earth and vegetation re-established. Dens should be eliminated promptly because one burrow can lead to failure of a dam.

Different repair measures are necessary if a dam has been damaged by extensive small rodent tunneling or by beaver or muskrat activity. In these cases, it may be necessary to excavate the damaged area down to competent soil and repair as described in Section 7.2.1.

Occasionally, rodent activity will result in passages which extend through the embankment that could result in leakage of reservoir water, piping, and, ultimately, failure. In these cases, the downstream end of the tunnel should not be plugged since this will add to the saturation of the dam. Tunnels of rodents or ground squirrels will normally be above the phreatic surface with primary entrance on the downstream side of the dam, while those of beaver and muskrat normally exist below or at the water surface with entrance on the upstream slope. If a rodent hole is found that extends through the dam, the best procedure is first to locate the upstream end of the passage. The area around the entrance should be excavated and then backfilled with impervious material. This places a plug or patch at the passage entrance so that reservoir water is prevented from saturating the interior of the dam. This should be considered a temporary repair. Excavation and backfilling of the entire tunnel or filling of the tunnel with cement grout are possible long-term solutions, but pressure cement grouting is an expensive and sometimes dangerous procedure. Indeed, pressure exerted during grouting can cause additional damage to the embankment in the form of hydraulic fracturing (an opening of cracks by high pressure grouting). Thus, grouting should be performed only under the direction of an engineer.

7.2.6 Traffic damage control - As mentioned earlier, vehicles driving across an embankment dam can create ruts in the dam crest if the crest is not surfaced with roadway material. The roads can then collect water and cause saturation and softening of the dam. Other ruts may be formed by vehicles driving up and down a dam face. These ruts can collect runoff and result in severe erosion. Vehicles should be banned from dam slopes and kept out by fences or barricades. Any ruts should be repaired as soon as possible using the methods outlined in Section 7.2.1.

7.2.7 Mechanical maintenance - Proper operation of a dam's outlet works is essential to the safe and satisfactory operation of a dam. Release of water from a dam is normally a frequent or ongoing function. However, on some reservoirs used for recreation, fish propagation, or other purposes that do not require continual release of water, an operable outlet provides the only means for the emergency lowering of the reservoir and is therefore, essential for the safety of the dam.

If routine inspection of the outlet works indicates the need for maintenance, the work should be completed as soon as access can be gained. Postponement of maintenance could cause damage to the installation, significantly reduce the useful life of the structure, and result in more extensive and more costly repairs when finally done. More importantly, failure to maintain an outlet system can lead directly to failure of the dam.

The simplest procedure to insure the smooth operation of outlet gates is to operate all gates through their full range at least once and preferably twice annually. Many gate manufacturers recommend operating gates as often as four times a year. Because operating gates under full reservoir pressure can result in large outlet discharges, gate testing should be scheduled during periods of low storage. If this cannot be done, they should be operated during periods of low stream flow. If large releases are expected, outlets should be tested only after coordinating releases with water administration officials and notifying downstream residents and water users.

Operation of the gates minimizes the buildup of rust in the operating mechanism and therefore, the likelihood of seizure of the operating mechanism. During this procedure, the mechanical parts of the operating mechanism - including drive gears, bearings, and wear plates - should be checked for adverse or excessive wear, all bolts, including anchor bolts, should be checked for tightness, worn and corroded parts should be replaced, and mechanical and alignment adjustments should be made as necessary.

The way the gate actually operates should also be noted. Rough, noisy, or erratic movement could be the first signs of a developing problem. The cause of operational problems should be investigated and corrected immediately.

Excessive force should be neither needed nor applied to either raise or lower a gate. Most hoisting mechanisms are designed to operate satisfactorily within the maximum force of 100 pounds on the operating handle or wheel. If excessive force seems to be needed, something may be binding the mechanical system. The application of excessive force may result in increased binding of the gate or damage to the outlet works. If there does seem to be undue resistance, the gate should be worked up and down repeatedly in short strokes until the binding ceases, and/or the cause of the problem should be investigated. Of course, the problem should be corrected as soon as possible to assure the continued operability of the gate.

If a gate does not properly seal when closed, debris may be lodged under or around the gate leaf or frame. The gate should be raised at least 2 to 3 inches to flush the debris, and the operator should then attempt to reclose the gate. This procedure should be repeated until proper sealing is achieved. However, if this problem or any other problem persists, a manufacturer's representative or engineer experienced in gate design and operation should be consulted.

An outlet gate operating mechanism should always be well lubricated in accordance with manufacturer's specifications. Proper lubrication will not only reduce wear in the mechanism, but also protect it against adverse weather. Gates with
oil-filled stems (i.e., stems encased in a larger surrounding pipe) should be checked semiannually to assure the proper oil level is maintained. If such mechanisms are neglected, water could enter the encasement pipe through the lower oil seal and could cause failure of the upper and/or lower seals which in turn could lead to the corrosion of both the gate stem and interior of the encasement pipe.

The metal used in gate seats is usually brass, stainless steel, bronze, or other rust-resistant alloys. Older or smaller gates may not be fitted with seats, making them susceptible to rusting at the contact surfaces between the gate leaf and gate frame. Operation of gates should prevent excessive rust buildup or seizure.

For satisfactory operation, a gate stem must be maintained in proper alignment with the gate and hoisting mechanism. Proper alignment and support is supplied by stem guides in sufficient number and properly spaced along the stem. Stem guides are brackets or bearings through which a stem passes. They both prevent lateral movement of the stem and bending or buckling when a stem is subjected to compression as a gate is being closed.

The alignment of a stem should be checked during routine inspections. Alignment may be checked by sighting along the length of the stem, or more accurately by dropping a plumbline from a point near the top of the stem to the other end. The stem should be checked in both an upstream/downstream direction as well as in a lateral direction to ensure straightness. While checking alignment, all gate stem guide anchors and adjusting bolts should be checked for tightness. A loose guide provides no support to the stem and could cause buckling of the stem at that point.

If during normal inspection, the stem appears out of alignment, the cause should be repaired. The gate should be completely lowered and all tension or compression taken off the stem. Any misaligned stem guides should be loosened and made to move freely. The hoisting mechanism should then be operated to put tension on the stem, thereby straightening it, but the gate should not be opened. The affected guides should then be aligned and fastened so that the stem passes exactly through their centers.

Many outlet gates are equipped with wedges that hold the gate leaf tightly against the gate frame as the gate is closed, thus causing a tight seal. Through years of use, gate seats may become worn, causing the gate to leak increasingly. If an installation has a wedge system, the leakage may be substantially reduced or eliminated by readjusting the wedges.

Because adjustment of these gates is complicated, inexperienced personnel can cause extensive damage to a gate. Improper adjustment could cause premature seating of the gate, possible scoring of the gate seats, binding of the gate, gate vibration, leakage, uneven closing of the gate, or damage to wedges or gate guides. Thus, only experienced personnel should perform adjustments, and a gate supplier or manufacturer should be consulted to obtain names of people experienced in such work.

Ice can exert great force on and cause significant damage to an outlet gate leaf. Storage levels in a reservoir during winter should be low enough that ice cannot form behind a gate. To prevent ice damage, the winter water level should be significantly higher than the gate if storage is maintained through the winter or, if the reservoir is to remain empty over the winter months, the outlet should be left fully open. If operations call for the water level to move across the gate during the winter, a bubbler or other anticing system may be needed.

7.2.8 Electrical maintenance - Electricity is typically used at a dam to:

- Provide lighting
- Operate outlet gates
- Operate recording equipment
- Operate spillway gates
- Operate other miscellaneous equipment

It is important that an electrical system be well maintained. Maintenance should include a thorough check of fuses and a test of the system to ensure that all parts are properly functioning. The electrical system should be free from moisture and dirt, and wiring should be checked for corrosion and mineral deposits. Any necessary repairs should be completed immediately, and records of the repair work should be kept. Generators used for auxiliary emergency power must also be maintained. This work includes changing oil, checking batteries and antifreeze and ensuring that fuel is readily available.

7.2.9 Cleaning - As already suggested, the proper operation of spillways, sluiceways, approach channels, inlet/outlet structures, spillways, and/or outlets require regular and thorough debris control devices require regular and thorough debris removal and cleaning. Cleaning is especially important after upstream storms which tend to send more debris into the reservoir.

7.2.10 Concrete maintenance - Also as mentioned, periodic maintenance should be performed on all concrete surfaces to repair deteriorated areas. Concrete deterioration should be repaired immediately when noted; it is most easily repaired in its early stages. Deterioration can accelerate and, if left unattended, can result in serious problems or dam failure. An experienced engineer should be consulted to determine both the extent of deterioration and the proper method of repair.

7.2.11 Metal component maintenance - All exposed, bare ferrous metal on an outlet installation, whether submerged or exposed to air, will tend to rust. To prevent corrosion, exposed ferrous metals must either be painted or heavily greased. If painted, the paint should be appropriate and applied following the paint manufacturer's directions.

When areas are repainted, steps should be taken to assure that paint does not get on gate seats, gate wedges, or gate stems where the stems pass through the stem guides, or on other friction surfaces where paint could cause binding. Heavy grease should be used on surfaces where binding can occur. Because rust is especially damaging to contact surfaces, existing rust should be removed before the periodic application of grease.
Table 8.1 is a reference directory of occurrences and emergency actions to be taken if needed.

<table>
<thead>
<tr>
<th>OCCURRENCE</th>
<th>OVERTOPPING</th>
<th>WAVE EROSION</th>
<th>EMBANKMENT SLIDES</th>
<th>ERODING FLOWS</th>
<th>OUTLET FAILURE</th>
<th>MASS SLIDING</th>
<th>EMBANKMENT SATURATION</th>
<th>SPILLWAY BACKCUTTING</th>
<th>EMBANKMENT SETTLEMENT</th>
<th>LOSS OF ABUTMENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>EMERGENCY ACTION</td>
<td>HYDRAULIC</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Lower water level</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td></td>
<td>Increase outlet flows</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td></td>
<td>Controlled Breach</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td></td>
<td>Sandbags (increase freeboard)</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td></td>
<td>Plug leak entrance</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td></td>
<td>Close outlet</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>EROSION CONTROL</td>
<td>Sandbags</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td></td>
<td>Riprap</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td></td>
<td>Weight toe area</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>OPERATIONS</td>
<td>Inspect</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td></td>
<td>Monitor</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td></td>
<td>Repair &amp; maintain</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td></td>
<td>Emergency notification</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td></td>
<td>Operate at reduced level</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
</tbody>
</table>
CHAPTER 8
EMERGENCY ACTION PLAN GUIDELINES

8.0 THE EMERGENCY ACTION PLAN

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 extensive property damage and deaths. 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 stating the above purposes and listing actions that the owner, the operating personnel and local government authorities should take. A plan should include sections on:

**Purpose:** (indicated above)

**Situation:**

- A list of problem indicators (see the checklist included in Table 8.3)
- A summary of communities in the potential inundation zone and flood travel times

- A list of anticipated failure situations that can be used as a guide for appropriate responses such as:
  - Failure pending - structure can likely be saved with immediate remedial action
  - Failure imminent - structure may possibly be saved with immediate remedial action
  - Failure in progress - no chance to save the structure
  - Flooding expected or in progress upstream from the dam site
  - Any other conditions peculiar to this dam

**Execution:**

- A list of remedial actions to prevent failure (see Section 8.2.)
- A plan for notification of downstream communities that allows the greatest possible time to warn and evacuate residents should failure occur and a list of telephone numbers of emergency preparedness officials in each community (There is an important distinction between notification and warning. Notification is the responsibility of the dam owner; he or she must notify community emergency officials of impending failure. These officials must then warn the public and evacuate them from the inundation zone if necessary. Public warning processes need not be fully specified in the dam owners’ emergency action plan.)

**Resources and Coordinating Instructions:**

- A list of those who can be of assistance, related telephone numbers, and radio call signs
- A list of materials for use in remedial action; for example, sandbags, high intensity lighting for night repairs
A dam owner should make full use of other persons who are concerned with dam safety. Cooperative planning can greatly benefit all parties and result in a more concrete, integrated plan. People and organizations with whom a dam owner should coordinate emergency planning include:

**LOCAL PARTICIPANTS**

The dam’s owners, shareholders, and beneficiaries
Officials of nearby downstream cities and towns
Local police, county sheriff
Local emergency officials
Local fire department
County highway department
Local construction companies
News media serving the area (radio, TV, newspaper)
Nearby engineering firms
Professional diving services
Helicopter services
Hospital and/or ambulance services

**STATE AGENCIES**

State Engineers office
State Engineer
Dam Safety Branch
Local water commissioner
Division engineer
State office responsible for disaster emergency services
State Highway Patrol
Department of highways
Department of health

**FEDERAL AGENCIES**

Bureau of Reclamation
U.S. Forest Service
National Park Service
U.S. Army Corps of Engineers
Federal Bureau of Investigation
Federal Emergency Management Agency
Federal Energy Regulatory Commission
United States Geological Survey

A checklist to assist in the development of an emergency action plan is provided at the end of this chapter. A dam owner should use this list to develop a plan and to update the plan periodically thereafter as conditions change (see Table 8.3).

### TABLE 8.2
**POTENTIAL PROBLEMS AND IMMEDIATE RESPONSE ACTIONS**

<table>
<thead>
<tr>
<th>Potential Problems</th>
<th>Immediate Response Actions</th>
</tr>
</thead>
</table>
| **OVERTOPPING BY FLOOD WATERS** | - Open outlet to its maximum safe capacity  
- Place sandbags along the crest to increase freeboard and force more water through the spillway and outlet  
- Provide erosion-resistant protection to the downstream slope by placing plastic sheets or other materials over eroding areas  
- Divert flood waters around the reservoir basin if possible  
- Create additional spillway capacity by making a controlled breach in a low embankment or dike section where the foundation materials are erosion resistant |
| **LOSS OF FREEBOARD OR DAM CROSS SECTION DUE TO STORM WAVE EROSION** | - Place additional riprap or sandbags in damaged areas to prevent further embankment erosion  
- Lower the water level to an elevation below the damaged area  
- Restore freeboard with sandbags or earth and rockfill  
- Continue close inspection of the damaged area until the storm is over |
| **SLIDES ON THE UPSTREAM OR DOWNSTREAM SLOPE OF THE EMBANKMENT** | - Lower the water level at a rate and to an elevation considered safe given the slide condition. If the outlet is damaged or blocked, pumping, siphoning, or a controlled breach may be required  
- Restore lost freeboard if required by placing sandbags or filling in the top of the slide  
- Stabilize slides on the downstream slope by weighting the toe area with additional soil, rock, or gravel |
| **EROSIONAL FLOWS THROUGH THE EMBANKMENT, FOUNDATION, OR ABUTMENTS** | - Plug the flow with whatever material is available (hay bales, bentonite, or plastic sheeting if the entrance to the leak is in the reservoir basin)  
- Lower the water level until the flow decreases to a non-erosive velocity or until it stops  
- Place a protective sand and gravel filter over the exit area to hold materials in place  
- Continue lowering the water level until a safe elevation is reached  
- Continue operating at a reduced level until repairs can be made |

### 8.1 IDENTIFICATION OF EMERGENCY CONDITIONS AND INITIATION OF EMERGENCY RESPONSE ACTIONS

As discussed in earlier chapters, a dam owner should observe a dam structure and the dam site on a regular basis. Failure is most often caused by overtopping, water flowing through a dam’s key components, and weaknesses in the foundation and outlet works. As discussed in Chapters 5 and 6, a number of indicators can signal the beginning of problems that might cause failure.

At a minimum, a dam owner should include in the “Situation” portion of the plan a reminder to check the history and location of hazards which could lead to overtopping or other acute problems. These are discussed in detail in Chapter 3 and include:

- Earthquakes and active faults
- Flooding, storms, snow melt runoff
- Landslides

Reporting a Dam Safety Incident - When reporting a dam incident, all directions for example “left of” or “right from”) are from the point of view of an observer facing downstream.

When an “indicator” or dangerous condition appears, a dam owner or responsible agent must take immediate action. If failure is possible, that person should report the situation to state and local dam safety authorities immediately. The report should include:

- The name of the person making the report and how he or she can be contacted
FAILRE OF APPURTENANT STRUCTURES SUCH AS OUTLETS OR SPILLWAYS
- Implement temporary measures to protect the damaged structure, such as closing an outlet or providing temporary protection for a damaged spillway
- Employ experienced professional divers if necessary to assess the problem and possibly implement repair
- Lower the water level to a safe elevation. If the outlet is inoperable, pumping, siphoning, or a controlled breach may be required

MASS MOVEMENT OF THE DAM ON ITS FOUNDATION, (SPREADING OR MASS SLIDING FAILURE)
- Immediately lower the water level until excessive movement stops
- Continue lowering the water until a safe level is reached
- Continue operating at a reduced level until repairs can be made

EXCESSIVE SEEPAGE AND HIGH LEVEL SATURATION OF THE EMBANKMENT
- Lower the water to a safe level
- Continue frequent monitoring for signs of slides, cracking or concentrated seepage
- Continue operation at a reduced level until repairs can be made

SPILLWAY BACKCUTTING THREATENING RESERVOIR EVACUATION
- Reduce the flow over the spillway by fully opening the main outlet
- Provide temporary protection at the point of erosion by placing sandbags, riprap materials, or plastic sheets weighted with sandbags
- When inflow subsides, lower the water to a safe level
- Continue operating at a low water level in order to minimize spillway flow

EXCESSIVE SETTLEMENT OF THE EMBANKMENT
- Lower the water level by releasing it through the outlet or by pumping, siphoning, or a controlled breach
- If necessary, restore freeboard, preferably by placing sandbags
- Lower water to a safe level
- Continue operating at a reduced level until repairs can be made

LOSS OF ABUTMENT SUPPORT OR EXTENSIVE CRACKING IN CONCRETE DAMS
- Lower the water level by releasing it through the outlet
- Implement notification procedures
- Attempt to block water movement through the dam by placing plastic sheets on the upstream face
- Lowering water to a safe level

- The name of the dam, lake or reservoir, and river, stream, or tributary the dam is located on
- The location of the dam by the nearest highways, roads or towns and by township and section, and range and principal meridian, if known
- A description of the problem (for example, excessive leakage, cracks, sand boils, slides, wet spots, etc.)
- The location of the problem area on the dam relative to embankment height (for example, "about 1/3 up from the toe") and relative to the dam's crest (for example, 100 feet to the right of the outlet or abutment) and in terms of what part of the dam is actually affected (for example, upstream slope, crest, or downstream slope)
- A description of the extent of the problem area
- An estimate of the quantity of unusual flow as well as a description of flow quality (clear, cloudy, muddy)
- A reading of the water level in the reservoir relative to the dam's crest, spillway and/or the gauge rod
- An indication of whether the water level is rising or falling
- An indication of whether the situation appears to be worsening
- An indication of whether the problem appears to be containable or is an emergency
- The current weather conditions at the site
- Anything else that seems important

A reporting form is included in Appendix B of this manual. Owners should use it as a guide and supplement it with additional site-specific details.

Additionally, the items on the report form should be periodically reviewed by owners and operators who frequently visit the dam site. An up-to-date report form and accurate report will permit intelligent assessment of a problem situation and proper implementation of an emergency action plan.

Immediate Response Actions - Response actions should be listed in the "Execution" section of the emergency action plan according to the problem or indicators being addressed (as in Table 8.2).

8.2 GUIDELINES FOR EMERGENCY NOTIFICATION

An essential part of the "Execution" Section of an emergency action plan is a list of agencies/persons to be notified in the event of a potential failure. Names for this list should be obtained from and coordinated with local law enforcement agencies and local disaster emergency services offices. The list should include key people or agencies who can activate warning and evacuation procedures for the public or who might be able to assist a dam owner in delaying or preventing failure. The following agencies can offer emergency assistance if failure of a dam appears imminent:
- Local sheriff, police, and/or fire departments
- Local disaster emergency agency
- County engineer
- State department responsible for dam safety
- State disaster emergency services office

A copy of the notification list should be posted in a prominent, accessible location at the dam - near a telephone and/or radio transmitter, if possible. It should be periodically (once or twice a year) verified and updated as necessary. It should include individual names and titles, locations, office and home telephone numbers, and radio frequencies and call signals if appropriate. Special procedures should be developed for nighttime, holiday, and weekend notification and for notification during a severe storm when telephones
The notification element of an emergency action plan should be brief, simple, and easy to implement under any conditions. Notification of impending failure is the first step in the process that leads to public warning. A dam owner should be careful to quickly notify the key official responsible for warning and evacuating the public. Normally, this is the county sheriff or city police chief. Notification of that official is the clear responsibility of the dam owner who should know the roles and responsibilities of both the official and the agency that will carry out public safety actions. Often, if a reservoir is large, the potential inundation zone will extend for many miles, and failure will threaten several communities and counties. A dam owner should include the proper official for each jurisdiction in the notification plan, so all can be notified as quickly as possible, (use position titles for officials so that the plan does not require updating every time a person changes jobs).

Certain key information must be included in every notification plan including information about potential inundation areas and travel times for the breach (flood) wave. Inundation maps showing potential areas of flooding from a dam failure are especially useful in local warning and evacuation planning. Detailed information about the identification of inundation zones and the development of maps can be found by contacting a state engineer's office or local planning office.

### TABLE 8.3

**CHECKLIST FOR DAM EMERGENCY PLANS**

I. Development of Plan

A. Overview: Use format suggested in paragraph 8.0.

1. Are reporting procedures clear in showing what data must be collected and what information should be reported?

2. Are terms in the plan defined so that users will have no questions about the nature of the situation?
   a. failure vs. impending failure
   b. emergency situation vs. potential problem
   c. rapidly vs. slowly developing situation

B. Problem Identification

1. Are all indicators of potential failure covered in the plan?
   a. Slumping/sloughing
   b. Erosion
   c. Riprap displacement
   d. Slides on dam or abutment
   e. Increased amount of seepage
   f. Cloudy or dirty seepage
   g. Boils
   h. Piping
   i. Whirlpools (vortices)
   j. Settlement
   k. Cracks
   l. Bogs
   m. Sinkholes
   n. Abnormal instrumentation readings
   o. Failure of operating equipment
   p. Water in the intake tower
   q. Other

2. Are all emergency situations covered in the plan?
   a. earthquakes
   b. floods
   c. storms
   d. massive landslides
   e. volcanic eruptions
   f. fires
   g. civil disturbance
   h. sudden water releases
   i. other potential disasters

3. Does the problem identification section list all the possible locations of a problem?

4. Are the above elements, indicators and events sufficiently defined so that the user can understand them?

5. Does the plan identify the cause of the problem?

6. Can the user ascertain the seriousness of the problem? (i.e., when the problem becomes an emergency)

7. Can the user determine what action is needed?

8. Can the user ascertain exactly when to notify local officials and which local officials to notify depending on the nature of the problem?

9. Can the user determine what equipment or supplies are needed for each type of problem?

10. Does the format of the plan easily link problem identification with the action to take, notification to make, and equipment and supplies to use?

11. Does the plan include a list of historical problems or most common problems for the type of dam in question?

C. Notification

1. Does the plan contain a list of key agency personnel and show:
   a. their office and 24-hour telephone number
   b. the name of their alternate
   c. which officials to call first
   d. responsibilities of the officials

2. Does the plan show the dam tender or project manager's responsibility in the event of a total loss of communications?

3. Does the plan's format allow the user to find the name of the primary contacts quickly? Has the order of notification been prioritized?

4. Does the plan's list of local officials in charge of evacuation include:
   a. office and 24-hour telephone number
   b. names of alternates
   c. which officials should be contacted first
   d. at what point officials should be called
   e. how messages should be worded
5. Does the plan describe the communication system?
   a. under normal conditions
   b. when backup is necessary
   c. for own radios
   d. for those to be notified

6. Does the plan include procedures for downstream notification?
   a. downstream operators
   b. other dams
   c. industries
   d. other agencies
   e. recreational users

D. Local Coordination
1. Was the development of the plan coordinated with local officials?
   a. did agencies contribute
   b. was the plan integrated into the local plan

2. Do inundation maps provide sufficient information and explanation?
   a. is language understandable
   b. are terms explained
   c. is map usage explained
   d. are criteria explained
   e. is travel time shown
   f. are hazardous elevations shown
   g. is flood plain information available

E. Resources
1. Are resources adequately identified? Does the plan indicate how to locate emergency equipment?
   a. are equipment and sources specifically described with the contact name and telephone number included
   b. are supplies and suppliers specifically described with the name of the contact and telephone number included
   c. are repair material and erosion protection material described
   d. are memos of understanding to share resources with government entities described

F. Review
1. Was there a comprehensive review of the plan at the time it was developed? Was it:
   a. technically accurate
   b. workable
   c. in compliance with criteria
   d. sufficiently comprehensive
   e. presented effectively

II. Implementation of Plan
A. Local Coordination
1. Were emergency plans (including notification lists and inundation maps) sent to all appropriate officials? Is the list maintained?
2. Have local officials had a briefing or other explanation of the plan? Is a record of such briefing maintained? Did the briefing explain:
   a. basic project data
   b. maps
   c. communication networks
   d. points of contact
   e. notification procedures
3. Have effective lines of communication for critical conditions been set up?
4. Have the dam owner and local officials agreed on their relationship, roles and responsibilities during a dam failure. Is the agreement in writing?
5. Has the dam owner reviewed local evacuation plans and discussed them with local officials?

B. Training
1. Has a plan for exercising the plan been developed?
2. Have exercises been conducted? Is a schedule of exercises maintained?
3. Have the following elements of the plan been exercised?
   a. problem identification
   b. emergency scenarios
   c. notification of dam owner and operating staff
   d. notification of others
   e. communication system
   f. resource list
4. Were all appropriate personnel involved in the test?
   a. owner’s personnel
   b. dam safety personnel
   c. maintenance personnel
   d. support staff
   e. local officials
   f. contractors and suppliers

C. Personnel and Resource Readiness
1. Are all appropriate employees familiar with the emergency action plan?
2. Do all appropriate employees have access to the plan?
3. Have all appropriate personnel received training in the following?
   a. how to use the plan
   b. identifying a problem
   c. identifying the severity of a problem
   d. using the communication equipment
   e. using the notification subplan
   f. overall dam safety
4. Are key personnel available 24 hours a day?
5. Is the division of personnel into emergency response teams appropriate?
6. Do employees understand their roles during emergencies?
7. Do key employees have access to the dam during emergencies?
8. Are resources ready?
   a. equipment
   b. list of contractors
   c. supplies on hand or readily available

D. Updating and Reviewing
1. Is the plan reviewed at least annually?
2. Are notification procedures regularly updated?
   a. names and telephone numbers of key staff
   b. names and telephone numbers of local officials
   c. names and telephone numbers of contractors
3. Is the plan reviewed to make sure that:
   a. exercises are conducted
   b. personnel are trained
   c. communication equipment is maintained
   d. other equipment is maintained
   e. the downstream warning system is in place and operational
   f. any new problems are included
   g. inundation maps are still current