Training
Aids for
Dam
Safety

MODULE:

DAM SAFETY AWARENESS

TADS

A video presentation accompanies this workbook.

Training
Aids for
Dam
Safety

MODULE:

DAM SAFETY AWARENESS

TADS

A video presentation accompanies this workbook.

PREFACE

There are presently more than 80,000 dams in use across the United States. Like any engineering works, these dams require continual care and maintenance, first to ensure that they remain operational and capable of performing all intended purposes, and then to preclude endangering people and property downstream.

The safety of all dams in the United States is of considerable national, state, and local concern. Given that, the principal purpose of the TADS (Training Aids for Dam Safety) program is to enhance dam safety on a national scale. Federal agencies have responsibility for the safe operation, maintenance, and regulation of dams under their ownership or jurisdiction. The states, other public jurisdictions, and private owners have responsibility for the safety of non-Federal dams. The safety and proper custodial care of dams can be achieved only through an awareness and acceptance of owner and operator responsibility, and through the availability of competent, well-trained engineers, geologists, technicians, and operators. Such awareness and expertise are best attained and maintained through effective training in dam safety technology.

Accordingly, an ad hoc Interagency Steering Committee was established to address ways to overcome the paucity of good dam safety training materials. The committee proposed a program of self-instructional study embodying video and printed materials and having the advantages of wide availability/marketability, low per-student cost, limited or no professional trainer involvement, and a common approach to dam safety practices.

The 14 Federal agencies represented on the National Interagency Committee on Dam Safety fully endorsed the proposed TADS program and have underwritten the cost of development. They have also made available technical specialists in a variety of disciplines to help in preparing the instructional materials. The states, through the Association of State Dam Safety Officials, also resolved to support TADS development by providing technical expertise.

The dam safety instruction provided by TADS is applicable to dams of all sizes and types, and is useful to all agencies and dam owners. The guidance in dam safety practice provided by TADS is generally applicable to all situations. However, it is recognized that the degree to which the methods and principles are adopted will rest with the individual agency, dam owner, or user. The sponsoring agencies of TADS assume no responsibility for the manner in which these instructional materials are used or interpreted, or the results derived therefrom.

ACKNOWLEDGMENTS

TADS STEERING COMMITTEE

James R. Graham, Bureau of Reclamation, Chairman
Arthur H. Walz, Corps of Engineers
William S. Bivins, Federal Emergency Management Agency
Donald L. Basinger, Soil Conservation Service
Joseph J. Ellam, Association of State Dam Safety Officials
(Commonwealth of Pennsylvania)
Marshall L. Silver, U.S. Committee on Large Dams

TADS PROJECT MANAGER

Chris J. Veesaert, Bureau of Reclamation

TADS TECHNICAL ACTIVITIES COMMITTEE

Duane E. Bankofier, Chairman, Corps of Engineers
Robert L. James, Corps of Engineers, Past Chairman (Retired)
Norman Miller, Soil Conservation Service, Vice Chairman
Chris J. Veesaert, Bureau of Reclamation
Samuel M. Huston, Tennessee Valley Authority
Harold C. Buttrey, Tennessee Valley Authority (Retired)
Constantine G. Tjoumas, Federal Energy Regulatory Commission
Alan E. Pearson, Association of State Dam Safety Officials
(State of Colorado)

TADS SPONSORS (Representing the Interagency Committee on Dam Safety)

Bureau of Reclamation
Corps of Engineers
Federal Emergency Management Agency
Soil Conservation Service
Federal Energy Regulatory Commission
Tennessee Valley Authority
Forest Service
Bureau of Land Management
National Park Service
Bureau of Indian Affairs
Fish and Wildlife Service
Department of Energy
Nuclear Regulatory Commission
International Boundary and Water Commission

TADS SUPPORTING ORGANIZATIONS

Association of State Dam Safety Officials
U.S. Committee on Large Dams

TABLE OF CONTENTS

	Page
MODULE INTRODUCTION	i
UNIT I. MAJOR FEATURES OF DAMS	
INTRODUCTION	I-1
Introduction	I-1
TYPES OF DAMS	I-3
Introduction	I-3
Embankment Dams	I-3
Concrete Dams	I-5
Gravity Dams	I-5
Buttress Dams	I-6
Arch Dams	I-7
Composite Dams	I-8
Masonry Dams	I-9
Roller Compacted Concrete Dams	I-9
WATER CONVEYANCE STRUCTURES	I-10
Introduction	I-10
Spillways	I-10
Outlet Works	I-10
Penstocks	I-11
GEOLOGIC SETTING	I-12
Introduction	I-12
Geologic Considerations in Dam Safety	I-12
FACILITY EMERGENCY PREPAREDNESS	I-14
Introduction	I-14
Components of Facility Emergency Preparedness	I-14
Site Conditions	I-14
Site Procedures	I-15
Emergency Preparedness Equipment	I-15

Continued . . .

TABLE OF CONTENTS

	Page
UNIT II. DAM FAILURES AND IMPORTANCE OF DAM SAFETY	
HISTORICAL PERSPECTIVE	II-1
Introduction	II-1
Notable Dam Failures	II-1
CAUSES OF DAM FAILURES	II-6
Introduction	II-6
Causes of Failure	II-6
CONSEQUENCES OF DAM FAILURES	II-8
Introduction	II-8
Consequences of Dam Failures	II-8
UNIT III. DAM OWNER RESPONSIBILITIES AND LIABILITY	
INTRODUCTION	III-1
Introduction	III-1
Dam Failure Liability	III-1
LEGAL LIABILITY	III-3
Introduction	III-3
Theories of Legal Liability	III-3
Negligence	III-3
Strict Liability	III-3
Acts of God and Probable Maximum Floods	III-5
Risks of Complying With Minimum Standards	III-5
Risks Inherent in Design Trade-Offs	III-6
Limits of Liability	III-6
Summary	III-7
INSURANCE	III-8
Introduction	III-8
Insuring a Dam	III-8

Continued . . .

TABLE OF CONTENTS

Page

UNIT III. DAM OWNER RESPONSIBILITIES AND LIABILITY (Continued)

PUBLIC SAFETY AROUND DAMS AND RESERVOIRS III-10
Introduction III-10
Liability Related to Public Safety III-10
Owner Responsibilities III-11
Hazardous Areas III-12
Spillways III-12
Stilling Basins III-13
Outlet Works Intake Structures III-13
Power Intake Channels and Open Channel Conveyance Structures III-14
Walls, Cliffs, and Steep Slopes III-14
Power Lines III-14
Swimming Beaches III-15
Safety Precautions III-15
Signs III-15
Fencing III-17
Guard Rails III-17
Floating Barriers III-17
Safety Ladders III-17
Public Safety Awareness Programs III-18
Vandalism III-18
Governmental Responsibilities III-19
Local Government Roles III-19

UNIT IV. DAM SAFETY PROGRAMS

OBJECTIVES IV-1
Introduction IV-1
Importance of a Dam Safety Program IV-1

ELEMENTS IV-3
Introduction IV-3
People IV-3
Organization IV-3
Process IV-5

Continued . . .

TABLE OF CONTENTS

Page

UNIT IV. DAM SAFETY PROGRAMS (Continued)

PLANNING A DAM SAFETY PROGRAM IV-7
Introduction IV-7
Gathering and Reviewing Technical Data IV-7
Conducting a Dam Inventory IV-9
Assigning Hazard Classifications IV-10
Low Hazard Classification IV-11
Significant Hazard Classification IV-11
High Hazard Classification IV-11
Designing the Dam Safety Program IV-11
Identify Program Activities IV-12
Secure Funding IV-12
Obtain Technical Resources IV-13

CONDUCTING PROGRAM ACTIVITIES IV-15
Introduction IV-15
Operation and Maintenance (O&M) IV-15
Importance of an O&M Program IV-16
Components of an O&M Program IV-16
Emergency Action Plan (EAP) IV-18
Importance of an EAP IV-19
Components of an EAP IV-19
Dam Safety Inspections IV-21
Types of Dam Safety Inspections IV-21
Reviewing Project Data IV-23
Preparing a Field Inspection Plan IV-23
Conducting a Dam Safety Inspection IV-24
Documenting the Results of a Dam Safety Inspection IV-25
Written or Tape-Recorded Notes IV-25
Visual Records IV-26
Additional Information IV-27
Inspection Reports IV-27
Investigations and Analyses IV-27

Continued . . .

TABLE OF CONTENTS

Page

UNIT IV. DAM SAFETY PROGRAMS (Continued)

CONDUCTING PROGRAM ACTIVITIES (Continued)

Correcting or Mitigating Dam Safety Concerns IV-28
Evaluating the Safety of a Dam IV-28
Evaluating the Operation and Maintenance Plan IV-28
Evaluating the Emergency Action Plan: Regulators IV-29
Correcting Deficiencies IV-29
Determining the Need for Corrective Action IV-29
Recommending Corrective Action IV-29
Evaluating Alternative Actions IV-30
Making Structural Corrections IV-31
Taking Nonstructural Corrective Actions IV-31
Specific Corrective Actions IV-32

Appendix A: Glossary

Appendix B: References

LIST OF FIGURES

Figure #	Title	Page
I-1	Primary Components of a Dam	I-2
I-2	Types of Embankment Dams	I-4
I-3	Sectional View of a Gravity Dam	I-5
I-4	Simplified View of a Flat-Slab Buttress Dam	I-6
I-5	Simplified View of an Arch Dam	I-7
I-6	Composite Dam	I-8
III-1	Installation of Public Safety Measures	III-16

MODULE INTRODUCTION

MODULE INTRODUCTION

INTRODUCTION

Dams are man-made barriers generally constructed of earthen materials or concrete for the purpose of controlling or storing water for a variety of uses. They may be built across a water course or offstream. Dams vary in height from only a few feet to over 1,000 feet high, and can be miles in length.

Dams have been an important part of civilization for at least 5,000 years and were among the earliest engineering endeavors attempted by mankind. Ruins of ancient dams may be found in many places throughout the world where early civilizations thrived, such as Egypt, Babylonia, Persia, India, and China.

One of the earliest dams whose remnants still survive is the Sadd el-Kafara Dam located about 20 miles south of Cairo, Egypt. This dam has been dated to perhaps as early as the reign of Khufu, who was King of Egypt about 2900 B.C. The dam had upstream and downstream rubble masonry walls with gravel and earth fill between them. Sadd el-Kafara Dam attained a height of 37 feet and a crest length of 350 feet. However, a critical deficiency in the dam's design was that it had no spillway, and this apparently led to its failure by overtopping shortly after completion.

PURPOSES AND BENEFITS OF DAMS

Throughout history, dams have been constructed for many useful purposes, and today dams generally serve more than one function. Dams may be classified according to the primary purpose or function for which they were intended. Three broad classifications of dams based on function can be made: detention, storage, and diversion.

- **Detention dams** are constructed to retard and minimize the effects of flood runoff. The reservoir for a detention or flood control dam has significant capacity above normal reservoir levels (which may be quite low for dams devoted solely to flood control) to store all or a portion of anticipated flood runoff. The stored floodwater is then released at a rate that does not exceed the carrying capacity of the channel downstream. At some detention dams, the stored floodwater is allowed to seep into the foundation to recharge the ground water.

PURPOSES AND BENEFITS OF DAMS (Continued)

- **Storage dams** are constructed to impound water during periods of surplus supply for use during periods of deficient supply. Consequently, reservoirs for storage dams are maintained at a higher level than are reservoirs for detention dams. The stored water may be withdrawn as needed for a variety of purposes, including crop irrigation, livestock watering, municipal and industrial water supply, and electricity generation (via release through powerplant turbines).

- **Diversion dams** are ordinarily constructed to provide hydraulic head for diverting water from streams and rivers into ditches, canals, or other water conveyance systems.

It is generally acknowledged that if access is available, a reservoir will provide recreational benefits, such as swimming, boating, and fishing in the reservoir itself, and camping and picnicking nearby. In some cases, recreation may be the primary purpose of a reservoir, as well as the enhancement of fish and other wildlife.

ABOUT THIS MODULE

The purpose of this module is to create an awareness of the need for effective dam safety practices and dam safety programs. This is accomplished by providing information on . . .

- How dams are designed and constructed,
- The major features of a dam and how those features work,
- The role geology plays in the safety and stability of a dam,
- The causes and consequences of dam failure,
- Responsibilities and liability of a dam owner,
- What a dam owner can do to ensure public safety around dams and reservoirs,
- The elements of an effective dam safety program,
- The process by which a dam safety program may be conducted, and
- Corrective measures that may be taken when dam safety deficiencies are detected.

UNIT I.

MAJOR FEATURES OF DAMS

I. MAJOR FEATURES OF DAMS: INTRODUCTION

INTRODUCTION

A dam may be subdivided functionally into three basic components: the **body** of the dam, and water conveyance structures such as the **spillway** and **outlet works**.

While the configuration and construction materials of dams may vary from one design to another, each dam has the following primary components:

- **Upstream and Downstream Slopes or Faces.** The upstream slope or face is the inclined surface of the dam that is in contact with the reservoir. During normal operation, a large part of the upstream slope or face is usually under water.

  The downstream slope or face is the inclined surface of the dam away from the reservoir. Generally, the term *slope* is used in conjunction with embankment dams, and the term *face* with concrete dams.

- **Crest and Shoulders.** The crest is the top surface of the dam. Often a roadway is established across the crest for traffic or to facilitate dam operation, inspection, and maintenance.

  The shoulders are the upstream and downstream edges of the crest.

- **Heel and Toe.** The heel of a dam is the juncture of the upstream face of a concrete dam with the ground surface.

  The toe of a dam is the juncture of the downstream slope or face of all types of dams with the ground surface. The toe is also referred to as the downstream toe.

- **Foundation.** The foundation of a dam is the portion of the valley floor that underlies and supports the dam structure.

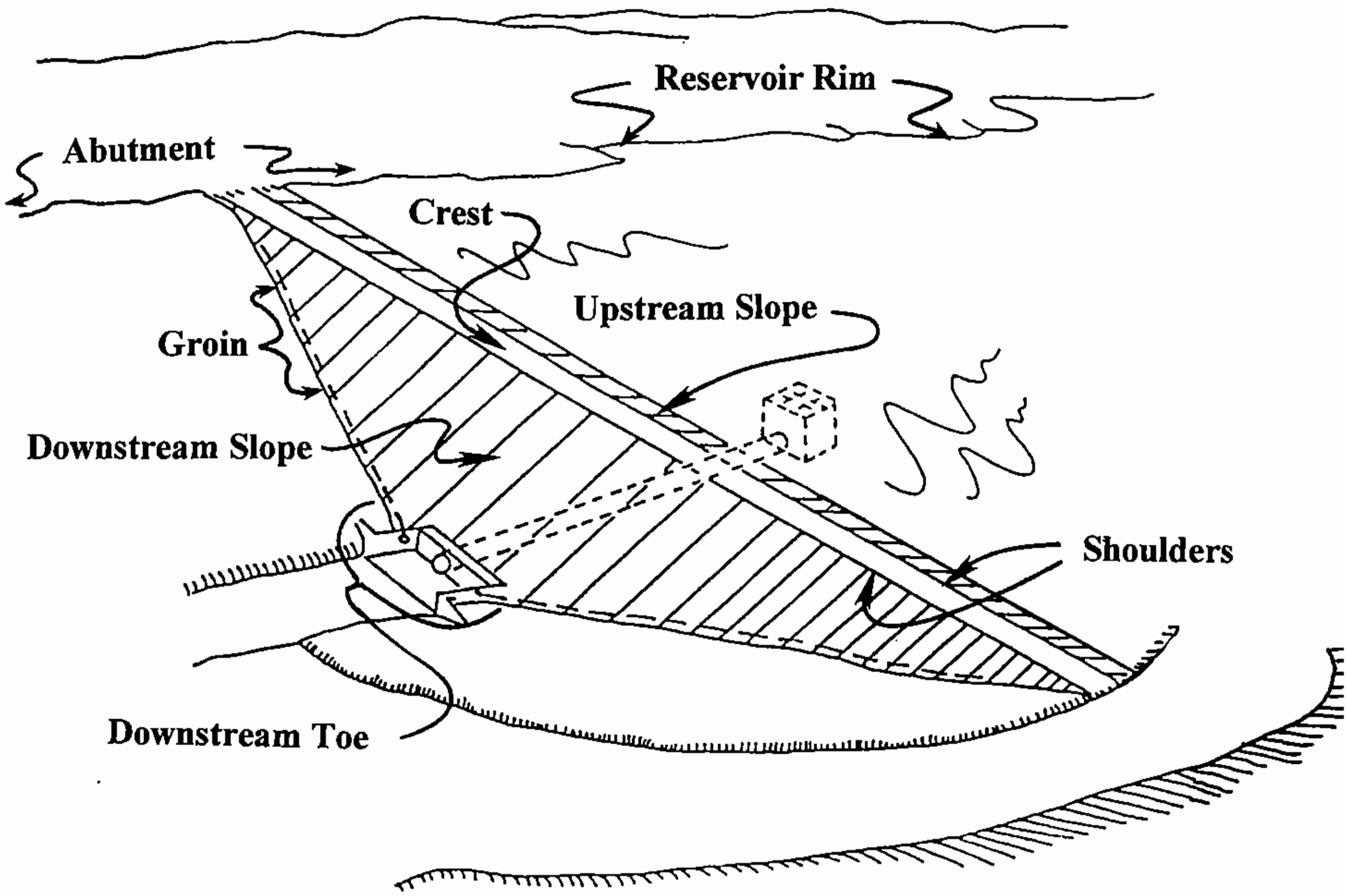
- **Abutments.** The abutments are those parts of the valley sides against which the dam is constructed. The contacts between the abutments and the slopes of an embankment dam are called the **slope-abutment interfaces** or **groins**.

- **Reservoir.** The reservoir is the body of water impounded by a dam.

Figure I-1 on the following page illustrates an embankment dam and labels the primary components.

I. MAJOR FEATURES OF DAMS: INTRODUCTION

FIGURE I-1. PRIMARY COMPONENTS OF A DAM



I. MAJOR FEATURES OF DAMS: TYPES OF DAMS

INTRODUCTION

The body of a dam is the water-retaining structure. There are many different types of dams and they are usually classified in terms of the materials from which the body of the dam is constructed, the form the body of the dam takes, or the method of construction. Different types of dams include:

- Earthfill dams
- Rockfill dams
- Arch dams
- Composite dams
- Masonry dams
- Roller compacted concrete dams

EMBANKMENT DAMS

The most prevalent type of dam, embankment dams, are those dams comprised of earthen materials generally obtained near the site. Embankment dams represent approximately three quarters of all dams in the United States and the majority of the dams around the world for two primary reasons: historically, they usually have been the most economical type of dam to build, and they can be adapted to most site conditions, whether competent bedrock or loose soil.

There are two major categories of embankment dams: earthfill and rockfill. Although several different definitions of earthfill and rockfill dams are used by various authors and organizations, the most commonly used definitions are the following:

- **Earthfill Dam:** A dam containing more than 50 percent, by volume, earthfill materials (fill composed of soil and rock materials that are predominantly gravel sized or smaller).

- **Rockfill Dam:** A dam containing more than 50 percent, by volume, rock materials (predominantly cobble sized or larger).

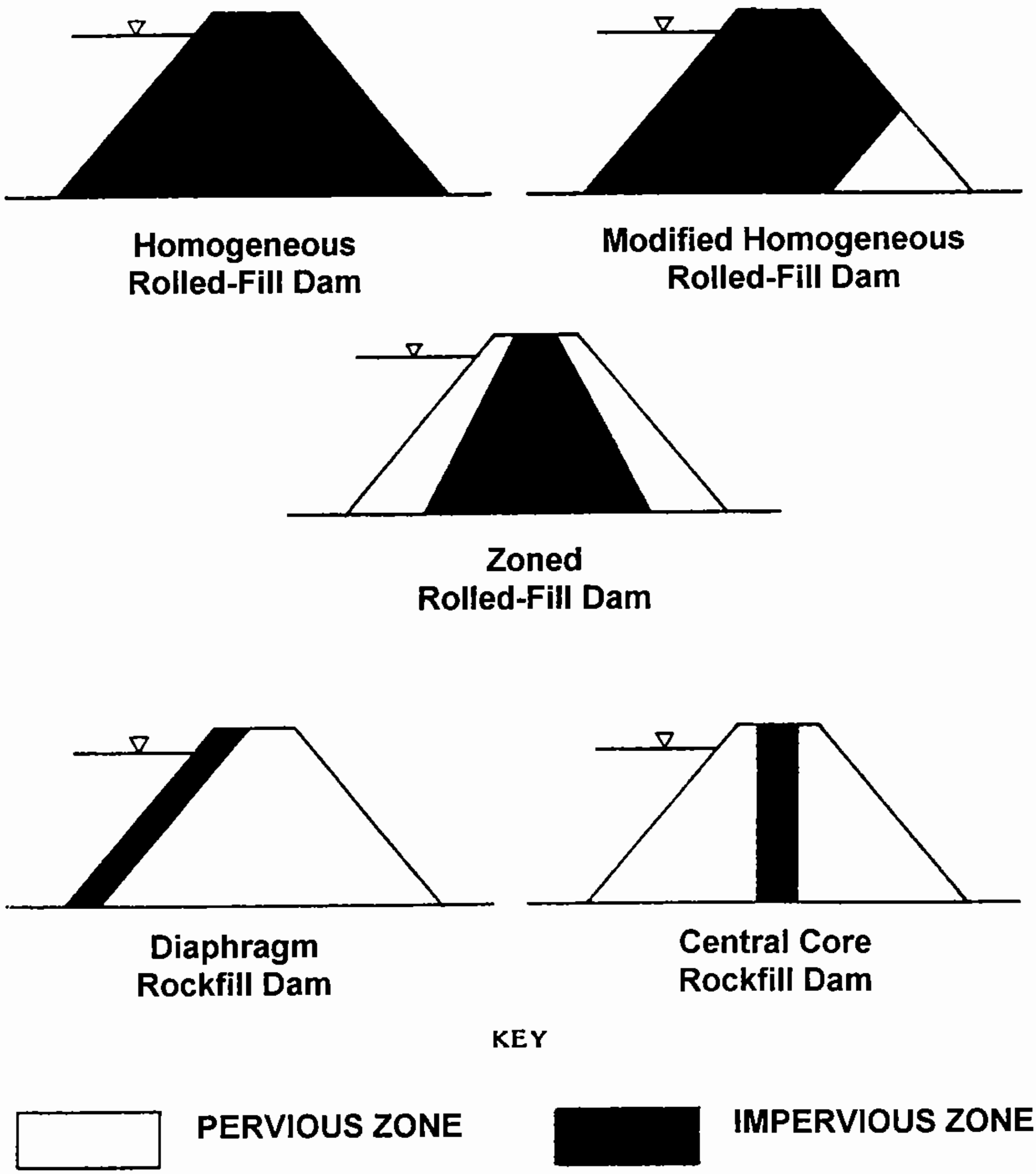
These two main types of embankment dams can be subdivided further based on the configuration of materials or construction methods. The TADS module Inspection Of Embankment Dams provides details on the different types of embankment dams and how they perform under the loads and pressures imposed upon them by a reservoir.

Figure I-2 on the following page shows the common types of earthfill and rockfill dams.

I. MAJOR FEATURES OF DAMS: TYPES OF DAMS

EMBANKMENT DAMS (Continued)

FIGURE I-2. TYPES OF EMBANKMENT DAMS



I. MAJOR FEATURES OF DAMS: TYPES OF DAMS

CONCRETE DAMS

A concrete dam is defined as a dam constructed mainly of cast-in-place or roller-compacted concrete. Concrete dams are thinner than embankment dams and impose more concentrated loads on the foundation and abutments.

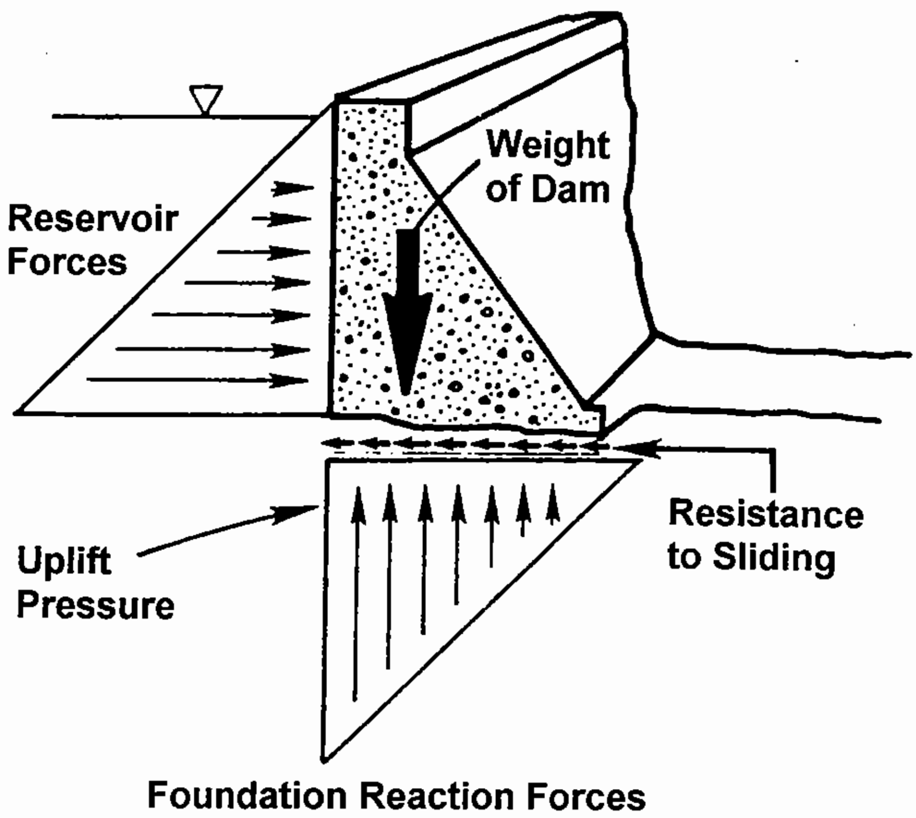
There are three basic structural types of concrete dams:

- Gravity dams
- Buttress dams
- Arch dams

Gravity Dams

Gravity dams are the most common type of concrete dam and the simplest to design and build. Massive and roughly triangular in cross-section, they depend on their weight and shape to withstand reservoir loads and transfer the loads to the foundation. Figure I-3 shows a sectional view of a gravity dam.

FIGURE I-3. SECTIONAL VIEW OF A GRAVITY DAM



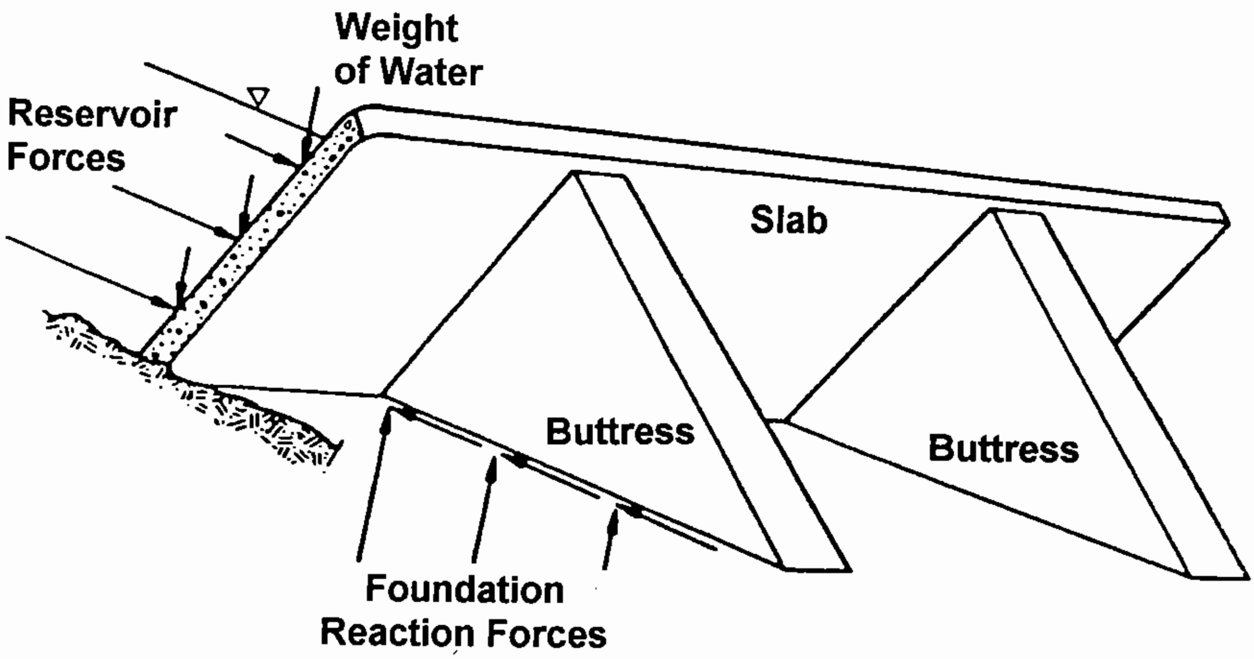
I. MAJOR FEATURES OF DAMS: TYPES OF DAMS

Buttress Dams

Buttress dams, a form of gravity dam, depend on their own weight and the weight of the water acting on the upstream face to maintain stability. They are comprised of two basic structural elements: a watertight upstream face and a series of buttresses, or vertical walls, that support the face and transfer the load from the face to the foundation.

One type of buttress dam, as shown in Figure I-4, is the flat-slab buttress dam, in which the upstream face is a relatively thin slab of reinforced concrete. Configurations vary, however, and you may encounter buttress dams with arched slabs or other configurations.

FIGURE I-4. SIMPLIFIED VIEW OF A FLAT-SLAB BUTTRESS DAM

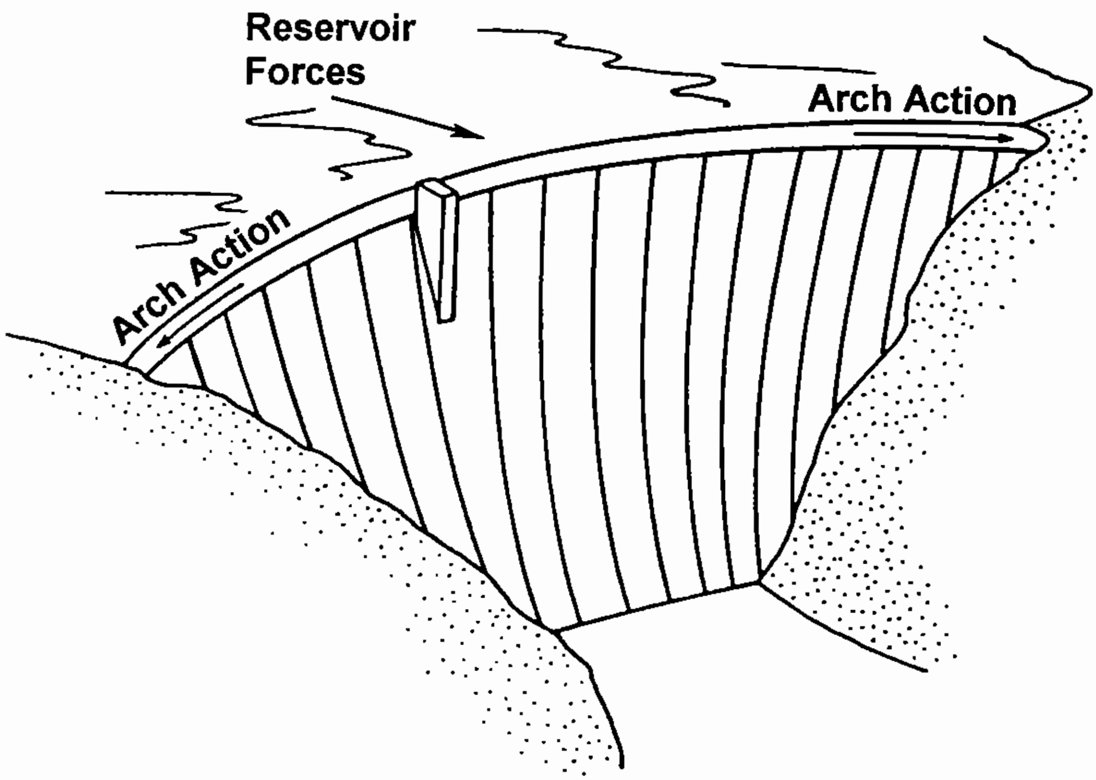


I. MAJOR FEATURES OF DAMS: TYPES OF DAMS

Arch Dams

An arch dam is a solid concrete dam that is curved upstream and is normally thinner than a gravity dam. Arch dams obtain most of their stability by transmitting the reservoir load into the abutments by the arch action. Figure I-5 shows a simplified view of an arch dam.

FIGURE I-5. SIMPLIFIED VIEW OF AN ARCH DAM



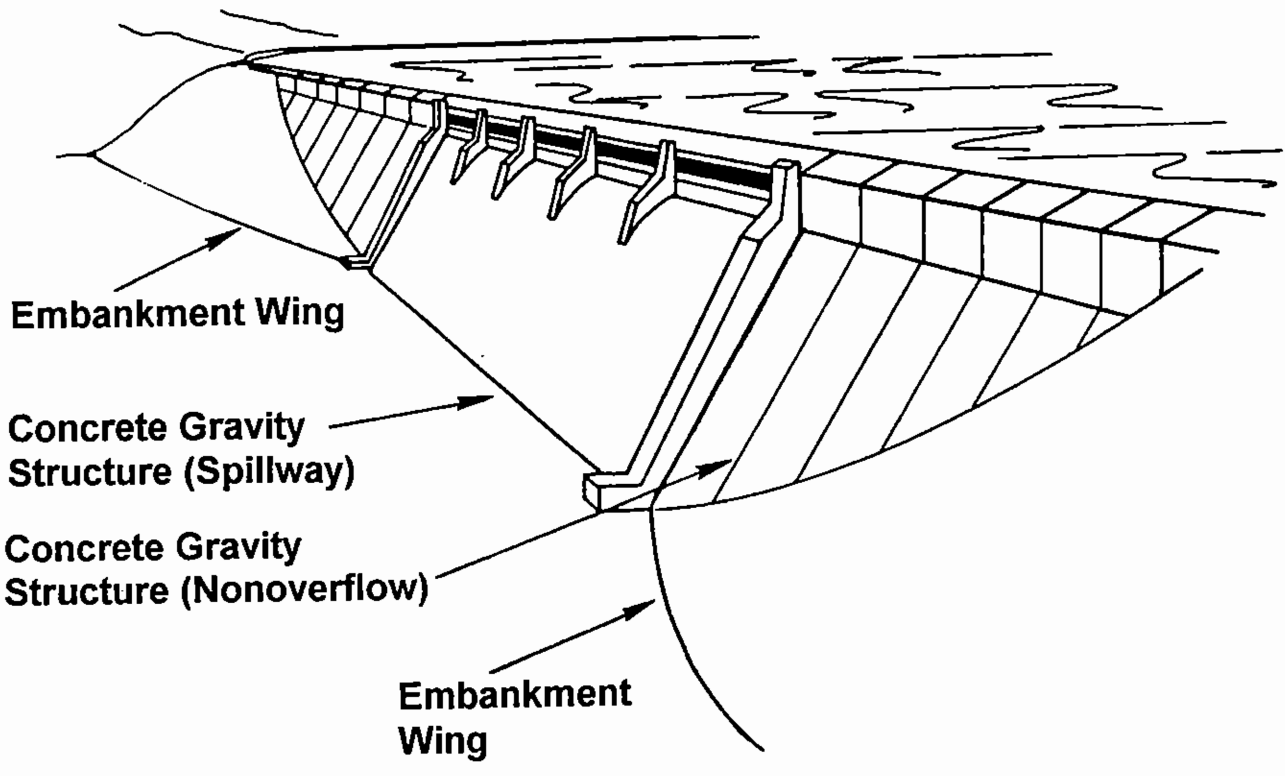
The TADS module Inspection Of Concrete And Masonry Dams provides details on the different types of concrete dams and how they perform under the loads and pressures imposed upon them by a reservoir.

I. MAJOR FEATURES OF DAMS: TYPES OF DAMS

COMPOSITE DAMS

A composite dam generally consists of a concrete gravity or buttress section in combination with earthfill or rockfill embankment sections. Composite dams incorporate the advantages of a concrete dam--the ability to act as the spillway (that is, to be safely overtopped)--with the advantages of an embankment dam--low construction costs and the use of locally available construction materials. Figure I-6 shows an example of a composite dam.

FIGURE I-6. COMPOSITE DAM



I. MAJOR FEATURES OF DAMS: TYPES OF DAMS

MASONRY DAMS

A masonry dam is a dam constructed mainly of stone, brick, rock, or concrete blocks joined with mortar. Most masonry dams are older gravity dams, although a few are arch dams. Masonry dams are usually considered in the same category as concrete dams because they function similarly.

Masonry dams may be categorized by the type of stone embedded in mortar or concrete. For example, a masonry dam made with very large, irregularly shaped stone (known as "cyclopean stone") is called a cyclopean masonry dam. Embankment dams with only a masonry facing are not considered masonry dams. Masonry dams are no longer built in the U.S. because of recent advances in concrete technology and the relatively high cost of masonry construction.

ROLLER COMPACTED CONCRETE DAMS

Roller compacted concrete (RCC) dams are a newer but rapidly growing type of dam construction. RCC dams consist of zero-slump concrete placed in horizontal lifts and compacted with vibratory rollers. RCC dams combine the advantages of the economy of a narrow cross section with the economy of earth dam construction techniques; hence, their growing popularity.

I. MAJOR FEATURES OF DAMS: WATER CONVEYANCE STRUCTURES

INTRODUCTION

Passage of water through and around a dam is accomplished by ***water conveyance structures***. These structures will differ, depending on whether the dam is an embankment dam or concrete dam, and on its purpose. Water conveyance structures include spillways, outlet works, and penstocks.

SPILLWAYS

The function of spillways is to pass flood flows (and in some cases normal flows) in a manner that protects the structural integrity of the associated dam. The flood magnitude a particular dam should be capable of accommodating (i.e., storing and/or passing) depends on the criteria established by the agency with regulatory control over the dam.

A dam may have more than one spillway, and in those cases, the spillways are often classified by the expected frequency of use. The primary spillway, also referred to as a principal or service spillway, is used first for passing flood flows. Auxiliary or emergency spillways are used to pass flood flows during rare, severe flooding.

Spillways have a great many configurations and designs, but may be classified as being either open channel or closed. Open channel spillways use channels and chutes to pass flows over or around a dam. Closed spillways use conduits or tunnels to convey flows through abutments or the dam itself. Either type of spillway may be controlled by gates or be free discharge spillways.

OUTLET WORKS

An outlet works is the normal means of releasing water impounded by a dam. These releases satisfy the purpose for which a detention dam was intended, such as irrigation, municipal or industrial water supply, etc. In addition, outlet works releases may be needed to satisfy minimum downstream flow requirements for water quality standards. In some cases, outlet works may be used along with the spillway to help pass floods. Lastly, outlet works serve as the means of lowering or draining the reservoir, if necessary, during a project emergency.

As with spillways, a dam may have more than one outlet works. The size, location, type, and design of an outlet works are influenced by the purpose(s) it is intended to serve. It should be recognized that a clear distinction cannot always be drawn between outlet works and spillways. In general, a pressurized, gate-controlled or valve-controlled conduit through a dam is considered an outlet works rather than a spillway, but outlet works may be ungated and carry unpressurized flow.

I. MAJOR FEATURES OF DAMS: WATER CONVEYANCE STRUCTURES

OUTLET WORKS (Continued)

Outlet works and spillways can share features and even be combined into one structure. Controlled outlet works may have gates or valves located upstream, midstream, or downstream, or in more than one location.

PENSTOCKS

Penstocks are pipelines or pressure conduits leading from the reservoir to the power-generating turbines. Penstocks are found only on dams with power-generating plants.

For more information on spillways, outlet works, and penstocks, refer to the TADS module entitled Inspection Of Spillways And Outlet Works.

I. MAJOR FEATURES OF DAMS: GEOLOGIC SETTING

INTRODUCTION

Before a particular type of dam can be selected for a site, certain geologic factors must be taken into account. The topography of a proposed dam site plays a major role in determining the type of dam to be constructed at that site. For example, a narrow stream channel between high, rocky walls might suggest the construction of a concrete arch dam with an overflow spillway. Low, rolling plains country might suggest an earthfill dam with a side channel spillway. The location of the spillway is an item that is governed very much by the local topography and geology, and generally has a significant impact on the final selection of the type of dam.

Another factor that determines the design of a dam is the earth materials found at the site. Site investigations may reveal that materials suitable for constructing a particular type of dam are available at the proposed site. For example, there might be suitable soils for constructing earth embankments, or sand, gravel, and crushable stone for concrete. In addition, the loads and stresses imposed by a dam and by the reservoir on the foundation and abutments, as well as the compressibility and strength of the foundation and abutment materials, will influence the type of dam to be constructed.

GEOLOGIC CONSIDERATIONS IN DAM SAFETY

The geologic areas important with regard to the safety of a dam are the:

- Foundation
- Abutments
- Reservoir Rim

The foundation, abutments, and reservoir rim are defined as follows:

- **Foundation.** The portion of the valley floor that underlies and supports the dam structure.

- **Abutments.** Those portions of the valley sides that underlie and support the dam structure, and are usually also considered to include the valley sides immediately upstream and downstream from the dam.

- **Reservoir Rim.** The boundary of the reservoir, which includes all areas along the valley sides above and below the water surface.

I. MAJOR FEATURES OF DAMS: GEOLOGIC SETTING

GEOLOGIC CONSIDERATIONS IN DAM SAFETY (Continued)

The foundation, abutments, and reservoir rim play an important role in the integrity and safety of the dam because they provide support for the dam, and contain the water in the reservoir area. In many instances, the cause of dam failure has not been with the structure itself, but with the geologic conditions in the foundation and abutments.

For detailed information about earth materials and how they perform under certain conditions, and inspection of the foundation, abutments, and reservoir rim, refer to the TADS module entitled Inspection Of The Foundation, Abutments, And Reservoir Rim.

I. MAJOR FEATURES OF DAMS: FACILITY EMERGENCY PREPAREDNESS

INTRODUCTION

While not a physical feature, the emergency preparedness of a facility reflects the relative ability of the facility and staff to respond effectively to emergencies. Emergency preparedness is assessed in order to define the hazards that a dam represents and to reduce loss of life and property damage that may be caused by flooding due to dam failure or unusually high flow through the spillway system.

COMPONENTS OF FACILITY EMERGENCY PREPAREDNESS

Components constituting facility emergency preparedness may be grouped into the following categories:

- Site conditions
- Site procedures
- Emergency preparedness equipment

Site Conditions

Site conditions include:

- **Downstream Hazard Classification.** A downstream hazard classification is a rating (e.g., low, moderate/significant, or high hazard) that is a categorization of the probable loss of life and property damage downstream from a dam, based on the results of breaching studies of the dam and an identification of the area downstream that would be inundated. Generally, hazard classification is based on the worst-case scenario of no action being taken to avoid the flooding resulting from dam failure.

- **Access.** Access to the site of the dam includes not only the capability of project personnel to reach the site under adverse conditions to operate electrical and mechanical equipment, but also the transportation of construction equipment and material to the site, if the nature of the emergency makes averting or alleviating the consequences of dam failure possible.

- **Security.** At a minimum, a dam's security system should effectively prevent trespassers from gaining access to and operating or damaging electrical and mechanical equipment. Additional security may be needed against other damage or destruction to the facility by trespassers.

I. MAJOR FEATURES OF DAMS: FACILITY EMERGENCY PREPAREDNESS

Site Procedures

Site procedures include:

- **Standing Operating Procedures.** The document containing instructions for normal operation, including the passage of floods, often is referred to as the Standing Operating Procedures (SOP).

- **Emergency Action Plan.** The Emergency Action Plan (EAP) contains procedures to be followed if structural problems, equipment malfunctions, or a natural event such as a flood or earthquake causes the design limits of a dam to be approached or exceeded.

In some cases, the SOP includes both normal operating procedures and the EAP. In other cases, two separate documents are maintained. The dam owner or operator is responsible for preparing and maintaining the SOP and the EAP.

Emergency Preparedness Equipment

The adequacy of emergency preparedness equipment is fundamental to the successful execution of an EAP. The EAP prepared by the dam owner/operator should contain descriptions or assessments of such equipment, which includes:

- **Communication Systems.** The available communication systems must be adequate during adverse situations to serve the needs of persons or organizations responsible for emergency operations.

- **Warning Systems.** Dams may have electrical/mechanical devices to alert onsite or remote personnel of adverse conditions. However, dam attendance is most often the only means of warning for most sites.

- **Auxiliary Power Systems.** In the event of failure of the primary power system, auxiliary power, which could be manual operation, must be available to operate mechanical equipment, lighting, and communication equipment, if necessary.

- **Remote Operation.** Remote operation is the ability to operate equipment, such as spillway gates, from a location other than the dam site. This may be important at sites that are not attended around the clock.

- **Reservoir Drawdown Capability.** During an emergency at a dam, the time required to lower the reservoir to relieve loading on the dam or minimize uncontrolled outflow often becomes extremely important. Reservoir drawdown is generally accomplished with the low-level outlet works.

UNIT II. DAM FAILURES AND IMPORTANCE OF DAM SAFETY

II. DAM FAILURES: HISTORICAL PERSPECTIVE

INTRODUCTION

The International Commission on Large Dams (ICOLD) reports that more than 8,000 people have died so far this century because of the failure of major dams. A closer examination nationally shows that there have been many additional lesser failures or serious incidents that almost led to failure.

The potential for loss of life, in itself, is reason enough to carefully monitor and maintain a dam. However, the loss of industry, farmland, and other property may also be devastating.

NOTABLE DAM FAILURES

> ***"The most appalling catastrophe in the history of mankind, due to failure of the works of man, and one of the worst great catastrophes due to any cause whatever, will make last week forever memorable."***

This statement began a report in the June 8, 1889, issue of ***Engineering News***, referring to one of the most infamous tragedies in the history of the United States: the Johnstown flood of May 31, 1889, caused by the failure of the South Fork Dam. The flood wave released by the collapse of this 70-foot-high embankment dam during a heavy rainstorm devastated the city of Johnstown, and killed more than 2,200 people.

Failure of the dam was attributed to erosion during overtopping. The wealthy owners of the dam, The South Fork Fishing and Hunting Club, had installed a screen across the spillway to keep fish from escaping. Debris in the reservoir lodged against this fish screen as the spillway was passing heavy rains. Eventually, the spillway became clogged, causing the dam to overtop and fail.

While the South Fork Dam failure has been the most devastating dam failure in this country in terms of loss of life, it has by no means been the only tragedy attributable to dams. It is ironic that even though dams represent a substantially greater potential threat to life and property than other civil works of man, dam owners have tended to assume that their dams will not experience major difficulty or fail, and public officials have been slow to implement dam safety programs to regulate the construction and continued safe performance of dams.

Unfortunately, there has been a direct correlation between the occurrence of dam failures and the passage of dam safety legislation and the commitment of manpower and money to ensure the safety of dams.

II. DAM FAILURES: HISTORICAL PERSPECTIVE

NOTABLE DAM FAILURES (Continued)

Just before midnight on March 12, 1928, the 205-foot-high St. Francis Dam, an arched concrete gravity dam located about 45 miles north of the city of Los Angeles, suddenly collapsed. The nearly-full reservoir, with a capacity of 38,000 acre-feet, was essentially emptied in about 70 minutes. The resulting flood wave attained an estimated maximum depth of 125 feet, and few people in the narrow canyon below the dam escaped with their lives. The death toll was placed at 450 and there was extensive property damage in the 50 miles downstream from the dam to the ocean.

There had been indications prior to the failure that all was not well with St. Francis Dam. Seepage through the abutments had reportedly been muddy for some time, a sign that abutment material was being removed with the seepage. Also, two large diagonal cracks running from the top of the dam to the base had appeared.

The chief engineer responsible for the dam, William Mulholland, was aware of these warning signs, but either chose to ignore or disbelieve them, because he continued to vouch for the dam's safety even during a site visit the morning of the failure.

Several theories have been proposed to explain the failure of St. Francis Dam, but it is generally believed that increasing hydrostatic uplift pressures acting on the base caused a tilting of the dam in a downstream direction until it finally gave way.

In the year following the failure of St. Francis Dam, the State of California enacted regulatory legislation that laid the foundation for one of the strongest state dam safety programs in the country.

California's legislation was strengthened by amendments two years after the failure of Baldwin Hills Dam in the city of Los Angeles on December 4, 1963. Baldwin Hills Dam was an embankment dam with a maximum height of 232 feet, but it impounded a small reservoir. Evidence of the impending failure was discovered several hours before the breach occurred in mid-afternoon, and an evacuation of the threatened population numbering more than 15,000 was hastily undertaken. Nevertheless, five people died as a result of the failure, and property damage was estimated at $11.3 million.

Investigations have concluded that failure was due to erosion of the foundation through a rupture in the reservoir lining that was caused by foundation movement.

II. DAM FAILURES: HISTORICAL PERSPECTIVE

NOTABLE DAM FAILURES (Continued)

It was two dam failures in 1972 that brought the subject of dam safety to the attention of the Federal Government. The first of these was the failure of the Buffalo Creek Tailings Dam in West Virginia, which gave way on February 26. The project consisted of a series of three unengineered embankments, one above the other, creating settling pools for mine wastes. No spillway for passing flood flows had been provided. Heavy rains had fallen in the Buffalo Creek drainage for several days preceding the failure, filling the upper pond. Prior to the failure, two deputy sheriffs had been called to the scene to aid evacuating people below the dam in the event of trouble, but they were dismissed by a senior official of the mining company. Shortly thereafter, inflow did overtop and fail the upper embankment, and the resulting flood wave, estimated as high as 20 feet, roared into downstream settlements with little or no warning, killing 25 people.

The second significant dam failure in 1972 occurred on June 9, during an extremely intense localized rainstorm over the Black Hills of South Dakota. As a result of the unprecedented rainfall, the 20-foot-high Canyon Lake Dam above Rapid City was overtopped and failed. The flooding from the rainstorm and dam break killed 237 people and destroyed much of the city, causing property damage estimated at $60 million.

Public concern over these two failures in 1972, led Congress to enact Public Law 92-367, the National Dam Inspection Act. This legislation mandated that the U.S. Army Corps of Engineers inspect non-Federal dams and conduct an inventory of all dams in the country. The Corps published its report entitled ***National Program of Inspection of Dams*** in 1975. The report included an inventory tallying some 49,500 U.S. dams (this was later increased to some 68,000 dams), a survey of state inspection practices, and inspection guidelines. Funding for dam inspections did not come until later.

Several more dams failed around this time. In February 1975, Walter Bouldin Dam in Alabama washed away, causing damages approaching $100 million but involving no loss of life. Bear Wallow Lake Dam, located in North Carolina, collapsed in February 1976, killing four and resulting in tens of thousands of dollars in damages. Then, on June 5, 1976, one of the most graphic dam failures in this country occurred when the U.S. Bureau of Reclamation's 305-foot-high Teton Dam in eastern Idaho failed during first filling with nearly a full reservoir. The visually spectacular failure occurred during daylight hours when photographic equipment was able to record it. Virtually the entire 250,000 acre-feet of water impounded by the dam were released within 6 hours. Somewhere between 11 to 14 people lost their lives, and property damage exceeded $400 million.

II. DAM FAILURES: HISTORICAL PERSPECTIVE

NOTABLE DAM FAILURES (Continued)

The failure of Teton Dam has been ascribed to internal erosion or "piping". However, precisely how the piping developed is still a subject of debate. The failure of Teton Dam was especially notable because this large modern embankment dam had been designed by a Federal agency with extensive dam-building experience. Largely as a result of this failure, Federal agencies responsible for dams began placing greater emphasis on their dam safety programs and in improving the safety of deficient Federal dams.

More than 95% of the dams in this country are privately owned dams, and the responsibility for regulating these dams rests with the individual states. However, in the mid-1970's, few states had adequately staffed and funded dam safety programs, and many even lacked the basic legislation necessary for regulation. Consequently, little was being accomplished relative to dam safety in the private sector.

In April 1977, President Jimmy Carter issued an executive order setting in motion activities that would lead to the development of the ***Federal Guidelines For Dam Safety***. These guidelines, subsequently published in 1979, apply to the management practices of all Federal agencies responsible for the planning, design, construction, operation, or regulation of dams.

Following the failure of two dams in 1977, the Laurel Run Dam in Pennsylvania which claimed 40 lives, and the Kelly Barnes Dam in Georgia which killed 38 people, President Carter directed the Corps of Engineers to begin the inspection of high-hazard dams (dams whose failure could cause loss of life). All states were encouraged to participate in the inspections and to implement dam safety programs if they had none. With financial assistance from the Corps, many states did initiate or enhance their programs. From 1978 to 1981, the Corps inspected nearly 9,000 dams under provisions of the National Dam Inspection Act. Almost a third of the dams inspected were found to be unsafe due to various conditions, but mostly because of inadequate spillway capacity.

During this same period, the Federal Emergency Management Agency (FEMA) was created and given responsibility to:

- Facilitate the exchange of information about dam safety between the Federal Government and the states,
- Encourage state legislation enhancing dam safety,
- Develop dam safety training programs and opportunities, and
- Develop programs to implement non-Federal dam safety.

II. DAM FAILURES: HISTORICAL PERSPECTIVE

NOTABLE DAM FAILURES (Continued)

However, even with this type of support, no legislatively mandated National Dam Safety Program exists.

Further assisting state dam safety programs has been the Association of State Dam Safety Officials (ASDSO), organized in 1984 by a small group of state officials. ASDSO membership has grown to encompass all 50 states and Puerto Rico. The association facilitates information exchange between the states and with the Federal Government; encourages state legislation enhancing dam safety; develops dam safety training programs, workshops, and conferences; and develops programs to implement non-Federal dam safety.

While much has been accomplished, progress in dam safety has been and continues to be slow. The cost of studying and correcting dam safety deficiencies is high, and especially hard hit are individual dam owners. There has been considerable focus on identifying less costly ways to address dam safety concerns. Regulators are examining the concept of acceptable risk, and looking at the cost of remedial action versus the consequences of failure in determining the appropriate course of action for a particular dam. There has also been considerable research into innovative and less costly alternatives to correcting deficiencies, such as overtopping protection for hydrologically inadequate embankment dams.

II. DAM FAILURES: CAUSES OF DAM FAILURES

INTRODUCTION

Dam failure may be defined broadly as the inability of a dam to fulfill its intended function, but for the purpose of this discussion, dam failure is considered to be the uncontrolled release of impounded water.

It is important to investigate and understand the causes of dam failures because knowledge of what went wrong at a failed dam may provide valuable insight into the adequacy of the design, construction, or operation of similar existing dams.

Significant advances in the methodologies that are applied to the design and building of new dams have also come about in this way. Although it should be understood that each dam is unique because no two dam sites and therefore no two designs are the same, similarities may be sufficient between a dam that has failed and an existing dam so as to conclude that an inherent weakness may be present in the existing dam, and corrective action should be taken.

CAUSES OF FAILURE

The causes of dam failure have been many, and different types of dams are more susceptible to some causes of failure than others. Some of the factors attributable to dam failure are:

- **Natural events.** Natural events, such as floods and earthquakes, can cause dam failure, particularly in older dams. Modern dams are generally designed to accommodate the largest possible flood that may be expected at the dam site, as well as the anticipated seismic activity. However, this does not preclude dam failure from unanticipated events.

- **Inadequate design or construction.** Many older dams have not been designed to safely handle the flood flows predicted by modern meteorological methods and longer storm flow records. This makes these dams susceptible to overtopping and possible failure. There are many examples of designs or construction methods no longer used that have been found to leave inherent weaknesses in a dam, making it susceptible to failure under certain conditions.

- **Inferior construction materials.** Materials used in the construction of a dam should be able to withstand the stresses and pressures associated with impounding water. Deficiencies in construction materials can create areas of weakness that may ultimately lead to failure of the dam.

II. DAM FAILURES: CAUSES OF DAM FAILURES

CAUSES OF FAILURE (Continued)

- **Age and lack of maintenance.** Older dams have been subjected to the ravages of time--wind and water erosion, years of loading imposed by the reservoir, and deterioration of the materials comprising the dam. Lack of proper maintenance can exacerbate the negative effects of aging, thereby creating unsafe conditions.

- **Instability of the foundation and/or abutments.** The foundation and abutments provide support for the dam. An unstable foundation or abutment can result in instability of the dam itself.

- **Seepage and leakage.** Seepage can cause internal erosion or piping of soil, solutioning of soluble rock, or excessive internal pressures and/or saturation, all of which can lead to failure of a dam. Leakage is the passage of water through concrete or metal structures, and can also lead to similar dam safety problems.

- **Failure of mechanical equipment.** Failure of mechanical equipment designed to release flood flows, such as spillway gates, can result in overtopping and subsequent failure of the dam.

- **Misoperation or improper operation.** Improper operation of gates and valves can cause binding or failure of equipment, which may in turn inhibit making necessary discharges.

Although these factors can contribute to dam failure, determining and categorizing the causes of dam failure is inexact for several reasons. Foremost is the fact that the destructiveness of the uncontrolled release of a reservoir generally destroys valuable evidence regarding the cause of failure. Investigators must then try to reconstruct events on the basis of incomplete information, and this becomes a subjective process where bias and opinion influence conclusions.

Secondly, a dam failure is usually attributable to several causes or circumstances; one of which may have been the direct or ultimate cause of failure, but there may be several indirect or secondary causes or circumstances. Weighing these various causes or circumstances is again subjective, and may lead to differing categorizations of the ultimate or reported cause of a failure.

Lastly, researchers disagree on the categories of dam failure themselves. One categorization of dam failures is the result of a survey done by the International Commission on Large Dams (ICOLD) and reported in its publication ***Lessons From Dam Incidents, USA***. These data were only for dams more than 15 meters in height. The three main causes of failure were found to be piping, foundation defects, and overtopping, with each cause having about the same rate of incidence.

II. DAM FAILURES: CONSEQUENCES OF DAM FAILURES

INTRODUCTION

As evident from the incidents described earlier in this unit, the consequences of dam failure can be catastrophic. In fact, few civil works hold as much potential for death and destruction as do dams. Thus, it is imperative that dam owners establish and faithfully carry out a well-conceived dam safety program.

CONSEQUENCES OF DAM FAILURES

In addition to the loss of life and property, including industry, farmland, and transportation facilities to name but a few, the failure of a dam means a loss of benefits provided by the dam, which may include municipal and industrial water supply, irrigation, power generation, and flood control. The economy of a city or even region could be devastated for years. Also receiving increasing recognition is the tremendous adverse effect an uncontrolled release of a reservoir can have on the environment.

All this considered, the importance of sound dam safety practices, particularly the following, cannot be ignored:

- Proper operation and maintenance
- Regular and thorough inspections
- Monitoring through instrumentation, where appropriate
- Timely correction of dam safety deficiencies
- Emergency action planning

UNIT III. DAM OWNER RESPONSIBILITIES AND LIABILITY

III. DAM OWNER RESPONSIBILITIES AND LIABILITY: INTRODUCTION

INTRODUCTION

Dams, by nature, embody potential risks to life and property. A fundamental need and prime responsibility of dam owners is the safety of their dams. Developing an effective dam safety program is the single most important measure a dam owner can take to reduce the possibility or consequences of dam failure.

When the operation or failure of a dam results in damages, liability may be assessed through various legal means. Damage may be caused by the uncontrolled escape of stored water, or controlled releases of unusually large flows.

Determination of liability is the legal means developed by society to recover damages due to a "wrong" (in this case, lack of dam safety). With a very limited number of exceptions, the general statement of liability for the owner or operator of a reservoir is:

> ***If water escapes from a dam, regardless of fault, the owner is responsible for all damages sustained.***

DAM FAILURE LIABILITY

In assessing the potential liability for a dam failure or damaging discharges, it is best to start with several premises.

- First, in the United States, each state is a separate jurisdiction free to impose its own theories of recovery as well as limitations on liability.

- Second, in today's litigious society, it is safe to assume that in the case of a catastrophic dam failure, extensive litigation will ensue. Lawsuits most probably will be filed against everyone remotely connected to a dam's existence, including the architects, engineers and contractors involved in the original construction, any contractors responsible for subsequent modifications, the dam owners and operators, and possibly the state engineer or private dam safety inspectors.

  In addition, the purchaser of an unsafe dam is liable for damages if the purchaser fails to make it safe or maintain it, even if the purchaser did not discover the safety problem, if a reasonable inspection should have discovered the problem.

- Third, should a dam failure result in loss of life, personal injury, or substantial property damage, it is fairly certain today that most jurisdictions will fashion a means to compensate the victims.

III. DAM OWNER RESPONSIBILITIES AND LIABILITY: INTRODUCTION

DAM FAILURE LIABILITY (Continued)

The basis for these premises is that the overriding purpose of modern tort law is to compensate an innocent victim for any injuries caused by the wrongful acts of another. A tort is simply a civil wrong for which an injured party may recover damages from the responsible party.

III. DAM OWNER RESPONSIBILITIES AND LIABILITY: LEGAL LIABILITY

INTRODUCTION

Whenever the potential for loss of life or property damage exists as a result of the existence of a dam, there is the question of legal liability: who is responsible should the dam fail? This section will address legal liability, complying with design and construction standards, and limits of liability.

THEORIES OF LEGAL LIABILITY

Two distinct theories of legal liability will be discussed with respect to dam safety: negligence and strict liability.

Negligence

Negligence is the most commonly utilized cause of action both in general tort litigation and in dam failure cases. Negligence is defined in terms of **the failure to exercise the standard of care of a reasonable person under similar circumstances**. This standard, in turn, is based upon the reasonable foreseeability of the risk.

The determination of whether this standard is met is generally based upon consideration of three components:

- The risk of an accident occurring,
- The magnitude of harm should the risk materialize, and
- The availability of alternatives.

The ultimate question, however, is not foreseeability, but in light of that foreseeability how a reasonable man would have acted, taking into account the potential magnitude of harm and the alternatives available.

Negligence can apply to the design, construction, operation, or maintenance of a dam. It may also consist of failing to inspect a dam, or negligence in the actual inspection of the facility. Negligence thus consists either of a failure to act in the first instance or, if one has in fact acted, the failure to act in a reasonable manner.

Because of the potential risk involved with a dam failure, the standard of care frequently imposed by courts is that one must use care commensurate with the undertaking; i.e., the duty of reasonable care is measured by the magnitude of the project. The degree of care required to prevent the escape of water is commensurate with the damage or injury that will result if the water does escape. If the risk is high enough, therefore, liability approaches strict liability.

III. DAM OWNER RESPONSIBILITIES AND LIABILITY: LEGAL LIABILITY

Strict Liability

The major alternative legal theory to negligence is strict liability. If such a theory is used, the degree of care used by the defendant or the reasonableness of his/her conduct is not considered.

The concept of strict liability has been widely extended to activities considered abnormally dangerous or ultrahazardous. The basis of strict liability for ultrahazardous activities is the risk or harm and the potential magnitude of that harm should the risk materialize. In such a situation, liability does not depend upon such factors as intent, recklessness, knowledge, negligence, moral blameworthiness, or any other degree of culpability. Nor does it depend on the degree of care the defendant exercised or failed to exercise. Rather, liability is based simply on the risks involved.

However, while strict liability for ultrahazardous activities has become widely accepted in the United States, its application to dam failures has been more limited. A slight majority of states reject strict liability in dam failures.

A major policy consideration today for imposing strict liability upon landowners who undertake abnormally dangerous activities is the high risk of harm posed to others. The landowners in this situation should bear the cost of harm caused to the innocent. The collection and storage of water in a dam upstream from a residential community may well constitute an abnormally dangerous activity, because the consequences of failure of such a dam are likely to be devastating.

Strict liability has also been imposed in situations where the dam owner/operator has constructed a dam, or part of a dam such as flashboards, expecting it to give way in a flood. In such a case, the potential risk of downstream flooding is so great that liability is imposed. Thus, while dam owners/operators are not insurers of the safety of their dams, they must use ordinary care in the operation of their dams. A dam owner cannot provide a device such as flashboards, with the intention that they give way in a flood, and then escape liability to those injured below the dam.

It should be noted that in a strict liability situation, the dam owner/operator is not an insurer for everything that could go wrong. Recognized exceptions to strict liability include:

- Acts of God
- Acts of agencies of the state (e.g., war)
- Malicious acts of third parties (e.g., sabotage)

Thus, it has been generally held that the owner of the water cannot be held liable when the escape of water has been caused by third-party acts that the owner could neither control nor anticipate.

III. DAM OWNER RESPONSIBILITIES AND LIABILITY: LEGAL LIABILITY

ACTS OF GOD AND PROBABLE MAXIMUM FLOODS

A commonly-asserted defense in dam failure cases is that the failure was caused by an "act of God"; i.e., an eventuality outside human contemplation, such as a catastrophic storm. If the storm is beyond human capacity to anticipate, then there is no liability.

The act of God defense generally entails unforeseeability by reasonable human intelligence and the absence of a human agency causing the alleged damage. Thus, if a similar storm had occurred before, could be anticipated using modern techniques, or was otherwise reasonably foreseeable, even if not probable, claiming an act of God will not successfully serve as a defense.

However, if the act of God is so overwhelming in and of itself so as to produce the injury independently of the dam owner's/operator's negligence, the dam owner/operator will not be liable. In other words, if the superior force would have produced the damage on its own, there is no liability. But if the dam owner's/operator's negligence coincides with the natural cause, there is liability.

In summary, an act of God defense generally fails if the event should reasonably have been anticipated in light of past knowledge, or if prior negligence on the part of the defendant exacerbates the situation. Foreseeability is based not only upon the historical past, but also upon what modern technology and science can predict.

RISKS OF COMPLYING WITH MINIMAL STANDARDS

Compliance with a generally accepted industry or professional standard of care, or with government regulations, establishes only the minimal standard of care. Courts may assess a higher standard of care, utilizing the "reasonable man" standard and foreseeability of risk as the criteria, particularly if reasonable prudence requires higher care.

The critical factor here is that courts retain the power to override professional or industry standards as inadequate. Judges and juries may find that the tragic consequences outweigh other considerations. Thus, compliance with government regulations or professional standards may not protect the owner/operator if reasonable prudence would justify a higher standard of care.

III. DAM OWNER RESPONSIBILITIES AND LIABILITY: LEGAL LIABILITY

RISKS INHERENT IN DESIGN TRADE-OFFS

While in most cases there are trade-offs between safety, performance (efficiency), and cost (economics), the practical reality is that in the eyes of a jury, trade-offs will seem callous when balanced against the loss of lives and property. The decisions of the designer or operator may well appear to constitute a "reckless disregard" of the rights of the victims, because the injury was foreseeable.

LIMITS OF LIABILITY

It should be noted that all of the preceding discussion concerning liability pertains to the release of previously stored water from a reservoir. In all circumstances to date, and in most states by specific statute, a reservoir owner may pass on all natural flood waters without incurring any liability downstream.

While the standard of liability imposed on a reservoir owner affords extremely limited relief, several states have enacted legislation that limits liability for damages in certain circumstances. In many other states, by statute or common law, the owner of the reservoir is entitled to utilize (i.e., release water to) the "normal high water line" of a stream without incurring liability for property damaged within the "normal" flood area. However, the definition of the limits within which no liability is imposed vary from place to place and may not be clearly designated on maps. Nonetheless, the right to utilize defined or "historic" floodplain regions downstream of a reservoir can provide substantial relief from strict liability for a dam owner.

With the recent insurance crisis and soaring liability insurance rates, many states are considering legislation that would limit either the basis of liability or the amount of liability that can be imposed on a reservoir owner. Some states, for example, are considering legislation that would change the standard of liability for a reservoir owner from a standard of "strict liability" to one of proven negligence.

If coupled with a redefinition of negligent actions, changes in law regarding the basis of a reservoir owner's liability could have a significant effect. However, the trend during the past 25 years has been to broaden, not narrow, the scope of negligent behavior by imposing broad expectations of prudence and foresight. Even if standards of "strict liability" are replaced by standards of "negligence," in the case of a reservoir owner, because the criteria of reasonable care and foresight are broadly interpreted, the change may not greatly affect the actual standard of liability imposed.

III. DAM OWNER RESPONSIBILITIES AND LIABILITY: LEGAL LIABILITY

LIMITS OF LIABILITY (Continued)

In most cases, the damages compensable to the victim are relatively clear. The general purpose of damages is to compensate the victim for the loss; that is, to place the victim, as closely as possible, to the position he/she was in prior to the injury; in other words, "to make the victim whole."

Less easy to calculate, and thus much more speculative and subjective, are such intangibles as the pain and suffering incurred by the victim, as well as the value to be placed on any loss of life. In addition, a new, much more indefinite element of damages has entered the picture: emotional distress of the survivors.

SUMMARY

In summary, existing law holds a reservoir owner to the highest standard of care. It should be emphasized that tort law in general, whether the theory is negligence or strict liability, is moving in the direction of victim compensation. Most courts strain to invoke liability, particularly when personal injury or death is involved. The odds are substantial that regardless of the theory cited, the result will be a finding of liability in the case of a dam failure involving loss of life.

Pending legislation may limit liability in certain circumstances; however, the general statement remains unchanged: the owner is liable for all damages caused by water escaping from a reservoir--despite the best efforts of the owner.

III. DAM OWNER RESPONSIBILITIES AND LIABILITY: INSURANCE

INTRODUCTION

Insurance can provide liability and asset protection, and thus is important for dam owners. In many states a minimum level of insurance coverage is mandated by law; in others it is not. In any case, the level of insurance carried should be based on: state law, value of facilities at risk, potential downstream impacts, condition and age of the dam, likelihood of an accident occurring, and the cost of available insurance. In order to obtain insurance and get a reasonable rate, the dam owner will have to show that the dam meets all state requirements with regard to design, construction, and operation. This may mean that the dam owner will need to provide:

- Some form of inspection schedule with formal inspections being conducted by engineers, geologists, and/or other professional personnel in addition to routine inspections by owner/operator personnel. Findings from inspections should be documented and available for inspection by the insurer.

- Written indication, in the form of completed work orders or other proof of work completed, that action is being taken or was taken to remedy deficiencies found during dam safety inspections.

- Evidence of a proper and effective dam safety program.

- Evidence of an effective emergency action plan.

Insurance spreads risk among a large group of people and cannot only provide protection for the person or organization owning the dam, but also for employees and governing boards who may be held personally liable.

INSURING A DAM

When insuring a dam, the owner should select and involve a competent insurance agent or broker as early as possible. Whenever a dam project requires new construction, reconstruction, or renovation, any lender involved will be very interested in the adequacy of the dam owner's insurance program.

Types of coverage, availability, and cost will vary from time to time, so it is advisable to seek professional advice when considering the purchase of insurance. Some insurance companies and brokers specialize in issues related to dam failure. Recommendations of insurers can normally be obtained from insurance industry representatives or from the state agency responsible for dam safety. Not only can damage and liability be covered, the cost of business interruption, lost income, and workmen's compensation can also be provided.

III. DAM OWNER RESPONSIBILITIES AND LIABILITY: INSURANCE

INSURING A DAM (Continued)

Because of the many types of insurance protection required and available, the development of an effective insurance program requires care and planning. If you involve a qualified insurance agent in the early planning, and work diligently to define your insurance needs, then an effective and economic program can be developed. Insurance can spread and reduce potential loss and as such should be an accepted cost of doing business. Many persons have avoided this cost and have paid severely for their shortsightedness.

III. DAM OWNER RESPONSIBILITIES AND LIABILITY: PUBLIC SAFETY AROUND DAMS AND RESERVOIRS

INTRODUCTION

There has been an increase in the use of reservoirs for recreational activities and a corresponding increase in injuries and fatalities related to the use of these facilities. As a result, it is important that the area on and around dams and reservoirs be evaluated for potential hazards and appropriate steps be taken to either eliminate the hazards or warn and protect the public from the hazardous conditions.

LIABILITY RELATED TO PUBLIC SAFETY

In general, a public entity (in this case a dam owner/operator), may be liable if:

- It fails to warn or guard against injury from a known dangerous condition or a dangerous condition that it should have known about,

- It fails to properly construct or maintain in good repair any structure, recreational equipment, or substantial work of improvement utilized in the hazardous recreation activity, or

- An employee's gross negligence is the probable cause of injury.

A facility creates an unreasonable risk of injury if the owner knew or should have known of a risk and failed to either remedy the situation or take steps to prevent potential injury within a reasonable period of time. The owner/operator must discover any unreasonably dangerous condition and either correct it or warn potential victims of its existence within a reasonable period of time. The owner/operator does not have to *insure* against the possibility of injury, but *act reasonably* to prevent the possibility of injury. The courts often recognize that participants are sometimes injured in recreational activities and that there is not always a person or agency at fault.

It is the obligation of the owner/operator of a dam to take all reasonable action to minimize risk to the public of personal injury and loss of life. As a result, it is important that all facilities and the adjoining area around dams and reservoirs be inspected to identify potential hazards to the public and operating and maintenance personnel so that all reasonable action can be taken to minimize the risk.

III. DAM OWNER RESPONSIBILITIES AND LIABILITY: PUBLIC SAFETY AROUND DAMS AND RESERVOIRS

LIABILITY RELATED TO PUBLIC SAFETY (Continued)

When visitors or trespassers are children, the dam owner has an even greater responsibility for safety. Children are generally unable to understand the danger certain conditions at a dam may pose. It is the responsibility of the dam owner/operator to protect children from those dangers by anticipating what parts of the facility would be particularly attractive to children, and taking measures to protect those areas. For example, signs alone may not adequately warn children and security fencing may be necessary.

The courts have indicated that there is no duty to remedy dangerous conditions that present an obvious risk that children would be expected to appreciate and avoid. Three risks considered to be obvious to a child are fire, water, and falling from a height. A hazard exists if a condition is not readily visible or there is a distracting influence that makes it likely that a child will not discover or appreciate the hazardous condition.

For liability to be assigned, a public entity must have either known or should have known that a particular condition existed, and also have known the danger created by that condition, but failed to act in a reasonable period of time to correct that condition.

For liability to exist, it must be shown that:

- Some form of injury occurred,
- A dangerous condition existed at the time of the injury and caused the injury,
- The condition had the potential for causing the type of injury that occurred,
- A negligent or wrongful act or omission created the condition, and
- The owner/operator of the facility had knowledge of the condition and had adequate time to correct the condition.

OWNER RESPONSIBILITIES

The dam owner/operator is responsible for making and keeping the premises safe. The dam owner/operator must avoid conduct or conditions that could injure any person, even those who trespass. If a condition exists that poses a danger, the dam owner/operator is responsible for correcting it and/or posting warnings.

Ideally, the way to minimize risk to the public at a dam would be to completely eliminate access to the dam and the reservoir. However, in most cases, this would be impractical as well as economically and politically unjustifiable. Barring this alternative, risk can still be reduced by being safety conscious and, in most cases, exercising common sense.

III. DAM OWNER RESPONSIBILITIES AND LIABILITY: PUBLIC SAFETY AROUND DAMS AND RESERVOIRS

OWNER RESPONSIBILITIES (Continued)

The primary consideration of a public safety program at a dam site is the availability of public access and the number and type of visitors that can be expected at that site. If the facility is near schools, recreational areas, or residential areas, and is subject to frequent visits by children, particularly unsupervised children, then safety precautions should be more extensive than those at a facility that is isolated and seldom visited by the public.

A good public safety program consists of a formal inspection of an area for site hazards and safety features. Public safety inspections should be performed at frequent intervals and at times of the year where changed conditions are likely, such as during or following heavy public visitation or following natural events such as floods, rainstorms, or a spring thaw.

Safety inspections should be documented and proposed remedial action noted. As deficiencies are addressed and remedial actions completed, the completion dates should be noted. Any accidents that occur at a site, whether they result in injury or death, should be documented along with the apparent cause of the accident. Immediate action must be taken to correct public safety deficiencies that may have contributed to the accident. Where possible, state or local entities should be consulted regarding public safety programs.

HAZARDOUS AREAS

The paragraphs below describe some of the most common areas around a dam considered to be public safety hazards.

Spillways

Spillways represent, in most cases, the single most hazardous condition at dams and may account for the largest number of injuries and fatalities to visitors to a site. Spillways can be particularly dangerous where the crest is wide and there are few visual cues for individuals upstream that would indicate the presence of a spillway. Generally, by the time the spillway becomes apparent, the increasing velocity of the current can make it difficult or impossible to reach safety and avoid being washed over the spillway crest. Severe injuries may result by passing through a spillway chute where baffle blocks, debris and other obstructions, or severe hydraulic conditions may be present.

All areas around spillways should be restricted by some form of barrier. The area upstream of spillway intakes should have a floating barrier and signs that prohibit boating, fishing, swimming, and any other form of recreation inside the restricted area.

III. DAM OWNER RESPONSIBILITIES AND LIABILITY: PUBLIC SAFETY AROUND DAMS AND RESERVOIRS

Spillways (Continued)

The area adjacent to spillway chutes can be hazardous, particularly if the chute walls do not adequately extend above the surrounding ground surface. Some form of fencing should be installed on the top of the wall and in a manner that prevents a person from standing on top of the wall inside the fencing.

Stilling Basins

Stilling basins downstream from spillways, outlet works, and power houses can be a significant hazard because of the changing flow conditions and because of turbulent flow. Whirlpools and hydraulics may develop in the stilling basin under certain discharge conditions that can prevent escape from the stilling basin by swimmers or boaters.

Currents created by stilling basins can be so strong that people or boats that have entered the stilling basin at what appears to be a relatively safe distance downstream from the area of turbulence may be pulled upstream into the turbulent waters. Hazardous flow conditions created by the geometry of different types of spillways and stilling basins may not always be evident to recreational users, whose experience and knowledge of varying flow conditions may be quite limited.

Access to all areas of stilling basins should be restricted by some form of barrier, signs, or fencing.

Outlet Works Intake Structures

Outlet works intake structures can be particularly hazardous when they lie at or just below the surface of the reservoir, because they typically cause strong currents in the reservoir, which can cause swimmers and boaters to be drawn into these structures. This hazard is particularly deceptive when these structures are operated on an intermittent basis and may be operated remotely.

Intake structures should be well marked and a barrier system constructed at a distance at which the maximum current will remain low enough to permit boaters and swimmers to escape. Warning signs should be posted in the vicinity of these structures indicating the potential hazard and restricting boating, fishing, swimming, and any other form of recreation in the vicinity of these structures.

III. DAM OWNER RESPONSIBILITIES AND LIABILITY: PUBLIC SAFETY AROUND DAMS AND RESERVOIRS

Power Intake Channels and Open Channel Conveyance Structures

Power intake channels and open conveyance structures present an attractive area for swimming, but are very dangerous because of the presence of slippery or steep side slopes that may prevent escape from the channel. In addition, the possible presence of siphons, power intake structures, and drop structures increases the danger.

Open channel structures may be very long, and limiting access with fencing may not be feasible in all cases. The potential frequency of visits to a particular portion of a facility by the general public must be considered when evaluating the need for safety facilities at a particular location. If a site is adjacent to schools or located in parks and recreational areas that are subject to frequent visits by children, then safety fencing should be used along with signs to limit access to these facilities.

Other safety features should be built into the channels themselves, such as escape ladders. Safety grates should be installed on the entrance to siphons, tunnels, drainage structures, and other intake structures to prevent a person from being washed into these structures.

Walls, Cliffs, and Steep Slopes

High walls, cliffs, and steep slopes are hazardous because these areas represent an attractive area to jump or dive into the water. Thousands of injuries resulting in paralysis and thousands of deaths occur each year in diving accidents.

Areas above cliffs and steep slopes may be frequented by visitors, resulting in a well-traveled path that invites additional visitors. In order to discourage use of a potentially hazardous or restricted area, any trail or path should be eliminated by physically obliterating the trail, and/or access to the area should be restricted through the use of fencing or other obstruction. Signs should also be used to discourage use.

Power Lines

Power lines can also pose a hazard for recreational users of reservoirs. Every precaution should be taken to eliminate the possibility of people or equipment making contact with electrical conductors. Ideally, power lines should not be present over or near streams, rivers, or reservoirs that can be used for recreational purposes.

III. DAM OWNER RESPONSIBILITIES AND LIABILITY: PUBLIC SAFETY AROUND DAMS AND RESERVOIRS

Swimming Beaches

It is particularly important to examine swimming areas for changed conditions. Water levels may fluctuate, changing the depth of swimming areas, or the floor of the swimming areas may be changed by erosion or deposition.

SAFETY PRECAUTIONS

Typical public safety precautions that can be used around a dam and reservoir are discussed below. Figure III-1 on the following page illustrates the installation of public safety measures at a dam and reservoir.

Signs

Signs should be used to direct, identify, inform, or warn the public. Signs are not intended to be used to confirm what is already general public knowledge. The following five guidelines should be considered when designing a system of signs. Signs should . . .

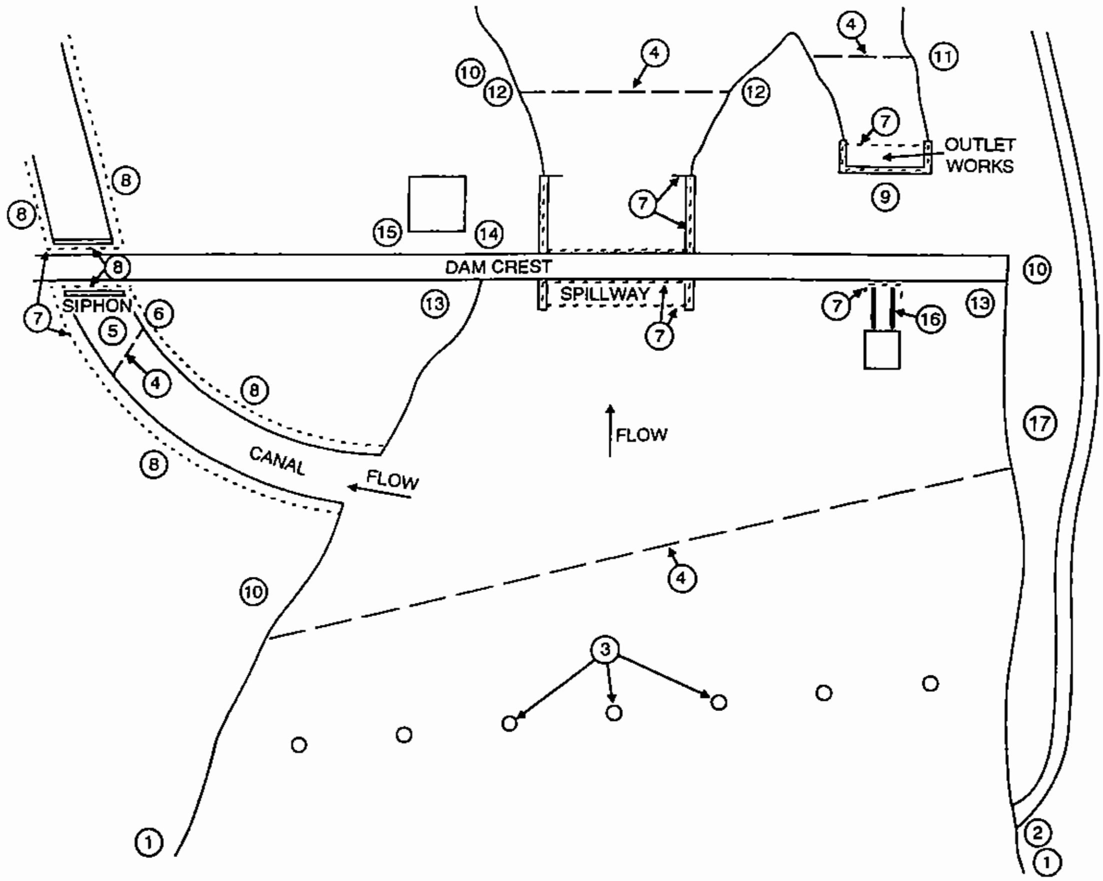
- Be located in a way so as to gain the attention of the visitor.
- Convey the nature of the hazard posed by the particular conduct.
- Warn of the hazard with the intensity commensurate with the outcome.
- Explain how to act to avoid injury.
- Explain the consequences of failing to obey the warning.

When posting warning signs, be consistent from point to point. Where the hazard is present over a large area such as a waterfront, large spillway, or conveyance structure, signs should be installed along the full length of the hazard. If signs are installed on an intermittent basis, an illusion of safety may exist for visitors to the area at a point where a sign is omitted. Under these circumstances, one could reasonably conclude that the prohibited activities are not only permitted, but are safe.

Signs should be maintained to assure that they are not blocked by vegetation or other obstructions. In addition, signs should be checked frequently to assure that lettering remains clear and legible and that the sign has not been vandalized or has deteriorated to the point where it has become ineffective.

III. DAM OWNER RESPONSIBILITIES AND LIABILITY: PUBLIC SAFETY AROUND DAMS AND RESERVOIRS

FIGURE III-1. INSTALLATION OF PUBLIC SAFETY MEASURES



1) Sign *"Danger--Dam Ahead Portage 100 Yards on Right Bank"*

2) Sign *"Portage Ahead"*

3) Buoys *"Danger--Dam Ahead No Trespassing Beyond Buoys"*

4) Floating Barrier

5) Safety Rack

6) Escape Ladder

7) Fencing

8) Sign *"Extreme Danger, Stay Alive Stay Out"*

9) Warning Siren and Warning Light

10) Lights

11) Sign *"Danger--Flows Subject to Sudden Changes. Do Not Pass Beyond This Point. Warning Siren Precedes Releases"*

12) Sign *"Danger--Extremely Turbulent Conditions When Spillway in Operation"*

13) Sign *"No Swimming, Fishing or Boating Within 600 Feet of Dam"*

14) Public Phone with Emergency Numbers Posted

15) Emergency Rescue Equipment

16) Guard Rail

17) Portage Trail

III. DAM OWNER RESPONSIBILITIES AND LIABILITY: PUBLIC SAFETY AROUND DAMS AND RESERVOIRS

Fencing

Fencing is one of the most common protective devices used to keep unauthorized persons and animals from getting into hazardous areas. The type of fencing may vary, depending on the:

- Hazardous condition,
- Expected frequency of visitation,
- Type of visitor, and
- Degree of site supervision.

Fencing should be installed in such a way so that it is very difficult to slip under, around, or over the end of the fence and enter a restricted area.

Guard Rails

Guard rails should be provided at areas of a dam or reservoir where vehicular access is provided and where steep slopes or dropoffs are present near public access roads. Guard rails should adhere to applicable local or Federal guidelines.

Floating Barriers

Floating barriers at swimming beaches are used to . . .

- Segregate swimmers from other recreation users (such as boaters),
- Delineate shallow areas from deeper swimming areas,
- Limit access to dangers such as areas with strong currents or dropoffs, and
- Provide a means of self-rescue in the event of an emergency.

Floating barriers should also be considered to limit access to hazardous areas of a reservoir, such as spillways, intake structures, stilling basins, and/or outlet works.

Safety Ladders

Safety ladders should be installed in areas to provide a means of escape where steep slopes or walls prevent a person from climbing to safety. In open channels with steep slopes, safety ladders should be provided at intervals that will allow self-rescue for people caught in the current and should be installed alternately on opposite sides of a channel. Sides should be well marked to increase visibility.

III. DAM OWNER RESPONSIBILITIES AND LIABILITY: PUBLIC SAFETY AROUND DAMS AND RESERVOIRS

Safety Ladders (Continued)

Safety ladders could present an attractive nuisance to visitors at a site, providing access to hazardous areas. Therefore, some means may be necessary to prevent the use of ladders for access rather than rescue.

Public Safety Awareness Programs

A good public safety awareness program will identify the most efficient ways to inform the visiting public of the hazards associated with the specific facility and to implement the program. A good program of public education can be very effective in reducing the potential for exposing visitors to hazardous conditions at the site. Frequently, the public is not aware of potential dangers and may take for granted that all accessible areas are safe during all conditions. Also, the public may be unaware of the rules of safe conduct or the specific measures taken to assure their safety.

Brochures, pamphlets, or signs can be used to explain hazardous areas and conditions, as well as rules and regulations that pertain to the site. Video presentations can be developed for specific audiences to provide recreational information as well as safety messages. In addition, information on specific steps to be taken in an emergency and phone numbers to call should be provided.

The location of emergency equipment such as telephones, ropes, and floatation devices should be noted and be readily apparent to a person unfamiliar with the site. The inclusion of a map denoting hazardous areas around a dam or on a water course is highly desirable and provides an easily understood illustration of areas of a site that should be avoided or that require caution. Signs providing detailed illustrations of site hazards can be invaluable in informing the public of potential hazards.

VANDALISM

Vandalism to public safety devices is a serious concern because this may significantly impair the public safety program. Cutting of fencing and removal of signs and rescue equipment could contribute to a serious accident at a site.

Vandalism cannot be eliminated but can be reduced by providing close supervision of a site, lighting critical areas, and allowing access to areas of the site that are deemed to be of low hazard to the public. Also, safety devices can be constructed of materials that are difficult to vandalize and located in a position that is difficult to access.

III. DAM OWNER RESPONSIBILITIES AND LIABILITY: PUBLIC SAFETY AROUND DAMS AND RESERVOIRS

VANDALISM (Continued)

Frequent surveys should be performed to determine the condition of all public safety devices. Where vandalism has occurred or where deterioration has taken place, prompt action is necessary to repair or replace public safety devices.

GOVERNMENTAL RESPONSIBILITIES

One of the fundamental functions of government is to protect citizens from threats to their health, safety, and general welfare. Reducing the consequences of dam failure is clearly a duty of Federal, State, and local governments that have joint and separate responsibilities to the public concerning dam safety.

Land use planning, public awareness programs, and emergency preparedness planning are typically conducted at the local level--the level of government most immediate and responsive to the dam owner. Federal agencies have technical expertise and can normally provide technical assistance when requested, but ultimately, each state is responsible for its own dam safety program.

Local Government Roles

Population settlement patterns and population growth strongly affect the costs of dam failures. More simply, if no one were allowed to settle in hazardous areas, few, if any, lives would be lost and little property would be damaged. Conversely, as settlement continues near dams and in inundation zones, the potential for disaster increases. "Low-hazard" dams are continually being transformed into "significant-hazard" and "high-hazard" dams as this settlement continues. Increased losses are inevitable unless significant land use measures are enacted to restrict the use of land in inundation zones. The strategies used will reflect Federal, State, and local efforts, but local government must make the critical decisions and only rely on State and Federal government for support. All elements of mitigation planning are based upon or affected by the way in which the affected land is used.

If the land has not been developed, the establishment of open space areas in potential inundation zones is a particularly effective way to reduce future costs of dam failure. Indeed, this is the best mitigation strategy to reduce future loss. Despite this utility, organized programs or strategies of land acquisition or settlement restriction exist in few states--usually because of strong opposition among developers and land owners.

III. DAM OWNER RESPONSIBILITIES AND LIABILITY: PUBLIC SAFETY AROUND DAMS AND RESERVOIRS

Local Government Roles (Continued)

If land is already under development, zoning measures to limit high population density can be useful. Also, the establishment of "green areas"--parks or golf courses--can be a low-cost means of limiting settlement in inundation zones. In some fully developed areas, flood-proofing devices (walls, barriers) may prove useful.

In much of the nation, land has already been developed and residential construction in inundation zones is already in place. People who live in such areas may have a false sense of security and not be aware that a hazard exists.

Experience has shown that simple warning and evacuation procedures can save a significant number of lives. Clearly, communities downstream from a dam should establish an early notification and warning system.

The stimulation of public awareness of this hazard and the development of warning and evacuation plans is the responsibility of local government. The utility of such efforts cannot be overlooked; the aggregate return will be large over the long term.

Existing levels of awareness vary across the nation. Some people are fully aware of their exposure to this hazard while many do not even realize that they reside in an inundation zone. Obviously, tourists are usually less aware than permanent residents; campgrounds, for example, do not normally post signs that point out the existence of a dam hazard. Clearly, awareness is the first step in mitigating the hazard and increasing safety.

Thus, counties, cities, towns, and smaller unincorporated communities urgently need:

- To develop programs to increase awareness of existing dam failure hazards, and more specifically, of who is in danger.
- To develop plans for warning and evacuating the population.
- To increase public familiarity with plans through publications, well-publicized exercises, and other means.

Usually, a public awareness program will be well received and generate confidence in government. Media--television, radio, and newspapers--are potentially the most effective way to educate people. Dam owners should encourage public awareness as well as warning and evacuation planning.

UNIT IV. DAM SAFETY PROGRAMS

IV. DAM SAFETY PROGRAMS: OBJECTIVES

INTRODUCTION

The best means of ensuring the safety of a dam is by instituting an effective dam safety program. A dam safety program is an organized effort that works to make the dams included in the program safe for continued operation. Laws, regulations, guidelines, policies, and prudent practice govern the conduct of dam safety programs.

A dam safety program evaluates the structural and operational safety of dams to identify deficiencies, and recommends either remedial repairs, operational restrictions, or modifications, as necessary. Analyses and studies are often required to confirm or better define a deficiency and to develop appropriate action.

People and organizations who own dams are responsible for the safe operation of their dams, and for the consequences of accidents or failures. Regulatory agencies have the responsibility to monitor dams for hazardous conditions that endanger life or property, and to enforce those laws, regulations, guidelines, and policies that direct owners to correct deficiencies.

All dam owners/operators and regulators with the responsibility for dams whose failures have the potential to cause loss of life must consider adopting a formal dam safety program. Such a program should be established by a person or organization regardless of whether they own one dam or many dams. The program should consider the same elements regardless of dam size.

Dam owners and dam regulators each operate dam safety programs. A dam will often be included in two different dam safety programs: one conducted by the owner or operator and the other conducted by a regulatory agency.

IMPORTANCE OF A DAM SAFETY PROGRAM

Dam safety programs help owners/operators and regulators to detect and correct dam safety deficiencies and thereby help to protect people and property from the disastrous effects of avoidable dam accidents and failures. The goals, then, of a dam safety program are to help owners/operators and regulators to . . .

- **Prevent accidents and failures at dams.** An effective dam safety program can help to ensure that potentially dangerous conditions are recognized before accidents and failures occur. Advanced planning allows emergency repair or procedural measures to be used when needed.

- **Detect and correct dam safety deficiencies.** Inspection, investigation, and analysis included in a dam safety program allow deficiencies to be recognized and remedies made. Early detection may avoid major risks to safety and major costs for correction.

IV. DAM SAFETY PROGRAMS: OBJECTIVES

IMPORTANCE OF A DAM SAFETY PROGRAM (Continued)

- **Protect investments.** A dam represents an investment that should be protected. A dam safety program is one means to protect that investment.

- **Meet legal obligations.** Dam owners and operators have certain legal obligations to meet. Owners and operators may have to comply with requirements contained in . . .

  - Federal, State, and local regulations

  - Land and water rights and rules

IV. DAM SAFETY PROGRAMS: ELEMENTS

INTRODUCTION

An effective dam safety program consists of three basic elements: people, organization, and process.

PEOPLE

The effectiveness of a dam safety program is probably best measured by the consciousness or state of mind of those people who have some reason to be involved with dams or to have an interest in the safety of dams. Those people include:

- **Government.** A regulating or legislative body should be interested in and conscious of dam safety because they should be looking out for the best interests of the public, and attempting to achieve a reasonable program to ensure the safety of dams that could endanger the public.

- **Technical Community.** Technical people associated with dams should be aware of the need for dam safety and the protection of the people who live downstream.

- **O & M or Project Personnel.** Project personnel have a duty to operate and maintain dams such that the dams will be able to store and discharge water *safely*, regardless of the situation. Because they are at the site, these people are in a position to detect and resolve problems early. These people represent the first line of defense in a dam safety program.

- **General Public.** It is inherent in human nature that preservation of life be considered a high priority. Consequently, it is reasonable for the public to place trust in government, the technical community, and project personnel to provide dams that will be safe throughout their lives.

ORGANIZATION

While it is impossible to guarantee that a dam will never fail, it is possible to minimize the chances of dam failure through a well-organized dam safety program. Here again, legislation is vitally important, because it is the device that defines the responsibility and authority and provides funding needed to get the program accomplished.

The independence of a dam safety program is also very important, and should be given a high priority when considering organization of a program. What is meant by an independent dam safety program? An independent program is one that can function without having to cater to outside, non-material influences, such as political pressures or special interests, that may have an agenda that is counterproductive to the goal of achieving safe dams.

IV. DAM SAFETY PROGRAMS: ELEMENTS

ORGANIZATION (Continued)

An independent dam safety program functions best when staff and budget are distinct from other elements of the organization, such as design. When designers are given the responsibility for both the design of new dams and the evaluation and remediation of existing dams, new design work invariably takes precedence because it has foreseeable economic benefit and is generally viewed as being more "glamorous."

There is also a potential conflict of interest in asking designers to evaluate the adequacy of their designs. It is difficult to be critically objective of your work or that of your organization. Self-evaluation does not have the advantages of offering a different perspective or experience.

In looking at how a dam safety program can be organized, two concepts emerge:

- Function-oriented program
- Dam-oriented program

In a function-oriented program, individual staff members perform certain program functions repeatedly, such as dam inspections, analyses, or remedial design as necessary for all program dams. As a result, the staff is highly specialized and skilled at performing specific functions, but less knowledgeable about individual dams.

In a dam-oriented program, individual staff members perform a variety of functions for a select few program dams. Because staff members perform many functions on a given dam, they become very familiar with those dams, but they are more generalized in their expertise.

Planning a dam safety program and conducting program activities are briefly discussed later in this unit.

IV. DAM SAFETY PROGRAMS: ELEMENTS

PROCESS

Finally, an effective dam safety program must have a well-defined process for identifying and correcting deficiencies. Briefly, this process includes:

- **Making an inventory of dams** to determine not only how many dams there are, but to obtain some basic data and information about each one, including preliminary hazard potential. This information is useful for prioritizing and scheduling work, and deciding initially if a dam should be in the program.

  Guidelines for including dams may vary from agency to agency. Some agencies exclude very small or low hazard dams from formal dam safety programs, but any dam whose failure poses a potential for loss of life should be included, regardless of size.

  Once the dam inventory is complete and assuming all the dams cannot be inspected in a short period of time, a priority for inspecting the dams should be established.

- **Preparing a Dam Safety File** (data file) for each individual dam that contains pertinent information on the dam. Items to be included in a Dam Safety File are described later in this unit. The data file is reviewed as part of the inspection, and referred to during analyses and remedial design, if needed.

- **Assigning a hazard classification** to determine the type and magnitude of losses (lives and property) that would occur should the dam fail. The hazard classification is then used for scheduling and prioritizing work.

- **Conducting inspections** to identify any potential problems and deficiencies. Visual observations, together with a review of the data file, including instrumentation, are the basis for evaluation of existing conditions.

IV. DAM SAFETY PROGRAMS: ELEMENTS

PROCESS (Continued)

- **Conducting analyses.** Analyses can be conducted in two phases:
  - The first phase is an assessment using available data and conservative assumptions to determine if there is a threat to the safety of the dam, to verify a problem and determine steps to alleviate the problem, or to determine if further analyses are required.
  - The second phase usually involves conducting field investigations, sampling, and laboratory testing to determine actual as-built conditions and material properties. After the analyses are completed, the results must be evaluated. Evaluation may indicate that no problems exist, or that problems have been verified. During the evaluation, certain alternatives for correcting these problems may become apparent.
- **Analysis should answer the question,** "Does a problem exist, and if so, how severe is the problem?"
- **Taking corrective action** if a problem or deficiency is verified. This includes:
  - Developing corrective action alternatives.
  - Evaluating and selecting the appropriate corrective action.
  - Implementing the corrective action.
  - Monitoring the dam to ensure the effectiveness of the corrective action, and to detect any new deficiencies that may develop.

IV. DAM SAFETY PROGRAMS: PLANNING A DAM SAFETY PROGRAM

INTRODUCTION

Planning a dam safety program involves the following activities:

- Gathering and reviewing technical data.
- Conducting a dam inventory.
- Assigning hazard classifications.
- Designing the dam safety program.

Dam safety programs may vary, depending on:

- The number of dams in the program,
- The complexity of maintaining and operating the dams, and
- Whether a regulatory function is required.

GATHERING AND REVIEWING TECHNICAL DATA

Effective planning demands good information. To begin outlining dam safety program activities, you first must compile an accurate and complete information base for all dams in the program. Collection and maintenance of data are ongoing activities that, if not already in place, should be established.

A number of different types of technical data provide an information base for planning a dam safety program. After implementation, these data will be the basis for program activity.

Dam owners and operators should establish a dam safety file by gathering and maintaining basic information about each dam in a dam safety program.

☞ **The following information is *essential* for evaluation of performance and will prove *vital* if the need for modification or repair should arise.**

- Engineering and geological data (including original calculations) used for design, construction, maintenance, repair, and/or modification of a project.
- Reports, permits, and licenses from regulatory agencies.
- Dam safety inspection reports.
- Operation and maintenance records.
- Instrumentation readings and data interpretation, including tabular records and graphic presentations of data.
- Drawings and photographs.

IV. DAM SAFETY PROGRAMS: PLANNING A DAM SAFETY PROGRAM

GATHERING AND REVIEWING TECHNICAL DATA (Continued)

The information listed also will be needed for review by engineers and geologists who perform inspections, investigations, and technical analyses.

Technical information for older dams often is hard to find. You may have to check with local libraries, design or construction firms or agencies, or the original owner of the dam for historic information.

Typically, most technical information is kept in file folders, looseleaf binders, or bound volumes. All technical information for a single dam may be physically stored in one file, or the information may be in separate files (embankment and spillway, for example).

Technical files are a good source of information for engineers and inspectors who perform dam safety inspections. Information can be compiled prior to the inspection and placed in a binder for use during the inspection. After dam safety inspections, copies of inspection reports, including recommendations, instructions, and records of when and by whom inspections were conducted should be added to the binder. Such binders can be kept readily available for future dam safety inspections, or for use in an emergency such as an earthquake or extremely heavy rainfall.

Owners/operators of power-generating facilities should establish additional files as required for facility operation by the Federal Energy Regulatory Commission.

Technical data and information to be used by technical personnel should be well-organized and placed in a Dam Safety File for each dam. The file may be a series of folders or perhaps a notebook with dividers labeled by subject area. The following subject areas might be considered:

- Aerial photographs
- Statistical summary
- Bibliography of records
- Listing of historical events
- Emergency preparedness
- Geology
- Hydrology
- Reservoir area
- Foundation
- Dam structure
- Spillway
- Outlet works
- Power plant

IV. DAM SAFETY PROGRAMS: PLANNING A DAM SAFETY PROGRAM

GATHERING AND REVIEWING TECHNICAL DATA (Continued)

- Mechanical equipment
- Other features
- Instrumentation
- Operation and maintenance reports
- Inspection reports
- Drawings

Further information on Dam Safety Files is presented in the TADS module entitled Preparing To Conduct A Dam Safety Inspection.

CONDUCTING A DAM INVENTORY

If you own or operate several dams, your Dam Safety Program must allocate resources among the dams. To match resources to needs, you must compare dams and judge relative priorities within the Dam Safety Program.

All dams in the Dam Safety Program need to be identified and information about them compiled to create a dam inventory. The inventory then can be organized into a dam inventory file. A Dam Safety Program that includes a large number of dams could make good use of a computerized inventory file. A variety of computerized dam inventory programs are available.

The Corps of Engineers conducted a survey between 1978 and 1980 that compiled data on all privately owned dams above a certain size as well as locks, Federal dams, and power-generating dams. Identification numbers were assigned to dams, and basic technical data were recorded. Survey results were reported in ***Recommended Guidelines For Safety Inspection of Dams***.

Information from the Corps of Engineers survey can serve as a base for building your dam inventory file. You can obtain survey data on dams within your Dam Safety Program by contacting the Corps of Engineers district that was responsible for the non-Federal Dam Safety Program for your State. (The data should be checked for accuracy before being incorporated in your file.)

The Association of State Dam Safety Officials (ASDSO) has developed a methodology to update the Federal inventory, including a standard file format. The updated inventory is titled the National Inventory of Dams, or NATDAM. Contact your State dam safety agency to determine whether NATDAM inventory data could be used to build your dam inventory file.

IV. DAM SAFETY PROGRAMS: PLANNING A DAM SAFETY PROGRAM

CONDUCTING A DAM INVENTORY (Continued)

You also may physically obtain data through surveys and measurements at the dam site.

Possible data sources for adding to the information compiled in the Federal inventory include:

- Aerial photography
- Permit and license files
- Field measurements
- Soil Conservation Service inventory
- Counties (for inventories of public facilities)

Your dam inventory file should include at least the following data:

- Federal inventory file information (verify the data: some are incorrect)
- Hazard classification
- Names and telephone numbers of owners/operators

Further information on gathering technical data to create a dam inventory file, as well as information on how to organize your Dam Safety Program, may be found in the TADS module entitled How To Organize A Dam Safety Program.

ASSIGNING HAZARD CLASSIFICATIONS

The hazard potential of a dam pertains to potential for loss of human life or property damage in the area downstream of the dam in the event of failure or incorrect operation of a dam. Hazard potential does *not* refer to the structural integrity of the dam itself, but rather the effects *if* a failure should occur.

The hazard potential of a dam is based on consideration of the effects of a failure during both normal and flood flow conditions, and includes consideration of recreational development and use. The hazard potential of a dam can be classified as low, significant, or high. **The hazard classification assigned to a dam should be based on failure consequences resulting in the greatest hazard potential.**

Hazard classification is the most important basis for inclusion in a Dam Safety Program. Any dam with the potential to cause loss of life or moderate property damage should be monitored through a Dam Safety Program. Downstream development may place any dam in this category.

IV. DAM SAFETY PROGRAMS: PLANNING A DAM SAFETY PROGRAM

ASSIGNING HAZARD CLASSIFICATIONS (Continued)

States and other regulatory agencies generally concentrate resources on high-hazard dams and inspect low-hazard dams less frequently (as long as downstream development is monitored to make changes in hazard classifications as needed).

Low Hazard Classification

Dams classified in the **low hazard** potential category generally either are located in rural or agricultural areas where the increased flooding due to failure may damage farm buildings, limited agricultural land, or township and country roads, or have a small storage capacity whereby the release from a failure would represent no danger to human life.

Significant Hazard Classification

Dams classified in the **significant hazard** potential category are usually located in predominantly rural or agricultural areas where damage from the increased flooding due to failure would be limited to isolated homes, secondary highways, and/or minor railroads, and may cause interruption in the use of relatively important public utilities, and/or some increased flooding of structures with possible danger to human life.

High Hazard Classification

Dams classified in the **high hazard** potential category are those located where the increased flooding due to failure could cause major damage to homes, extensive damage to agricultural, industrial, and commercial facilities, and/or damage to important public utilities, main highways, or railroads, and pose danger to human life.

The TADS module entitled Evaluation Of Hydrologic Adequacy provides more detailed information on evaluating the impacts of dam failure and assigning a hazard classification.

DESIGNING THE DAM SAFETY PROGRAM

The following steps are used to design a Dam Safety Program:

- Identify program activities
- Secure the necessary funding
- Obtain technical resources

IV. DAM SAFETY PROGRAMS: PLANNING A DAM SAFETY PROGRAM

Identify Program Activities

Determining the dam safety activities to be performed involves . . .

- Gathering technical data
- Identifying regulated dams
- Establishing program requirements

To begin outlining Dam Safety Program activities, you first must compile an accurate and complete information base for the dams in the program. Collection and maintenance of data are ongoing activities that, if not already in place, should be established.

A number of different types of technical data provide an information base for planning a Dam Safety Program. After implementation, these data will be the basis for program activities.

Examples of the types of data to be collected include records for individual dams, and an inventory of dams either owned or under regulation.

The TADS module entitled How To Organize A Dam Safety Program provides details on determining program activities.

Secure Funding

An effective Dam Safety Program must be assured of adequate long-term funding. If possible, a 5-year funding plan or budget should be prepared and updated annually to reflect additional information about the deficiencies that need to be corrected or investigations that must be initiated.

Funding a Dam Safety Program requires determining funding source(s) and estimating costs. Sources to pay for a Dam Safety Program (including the costs of repairs and modifications) might be:

- Taxes
- Assessments on members
- Fees
- Appropriations

To develop cost estimates, you need to identify all possible costs for operating your Dam Safety Program. Costs for a Dam Safety Program should be projected for at least a 5-year span. Many new programs have experienced crises because of a failure to establish funding far enough into the future.

IV. DAM SAFETY PROGRAMS: PLANNING A DAM SAFETY PROGRAM

Secure Funding (Continued)

Cost categories for Dam Safety Programs include annual costs and emergency and unanticipated costs. Examples of annual Dam Safety Program costs include . . .

- Personnel costs
- Contracted services
- Equipment, office space, and supplies
- Travel/per diem

Even if you have made very careful budget estimates, costs associated with emergencies and other unanticipated events may exceed your annual budget. For example, seismic activity may cause structural damage, or an inspection might reveal a hazardous condition that requires extensive modification or reconstruction.

Many dam owners and operators establish Emergency Reserve Funds to deal with emergency and unanticipated costs. To determine how much money should be set aside in your Emergency Reserve Fund, consider the following factors . . .

- Annual operation and maintenance expenditures
- Conditions at dam sites (topography, weather, seismic activity, etc.)
- Condition and vulnerability of features at the project site

The TADS module entitled How To Organize A Dam Safety Program provides more detailed information on securing funding.

Obtain Technical Resources

All the activities of your Dam Safety Program may be performed by your own employees, or some activities may be contracted. Functions contracted typically include . . .

- Operation and maintenance
- Technical services
- Training

Program size always plays a key role in determining the source(s) of technical services. Large programs tend to employ engineers and technicians, while smaller programs often find contracted services more cost-effective.

IV. DAM SAFETY PROGRAMS: PLANNING A DAM SAFETY PROGRAM

Obtain Technical Resources (Continued)

Investigate possible sources for technical services such as dam safety inspection, field investigations, and technical analyses. Some aspects of an Owner's Dam Safety Program may be provided by contracting with a Federal or State agency. These might include . . .

- Downstream hazard classification
- Dam design and construction
- Emergency Action Plan development
- Dam safety inspections
- Technical analyses and field investigations
- Cost estimates and feasibility studies for dam repairs and modifications (including cost/benefit analyses)

The TADS module entitled How To Organize A Dam Safety Program provides further details on obtaining technical resources.

IV. DAM SAFETY PROGRAMS: CONDUCTING PROGRAM ACTIVITIES

INTRODUCTION

Operating a Dam Safety Program involves conducting program activities, including . . .

- Performing operation and maintenance (O&M)
- Developing Emergency Action Plans
- Conducting inspections, investigations, and analyses
- Correcting or mitigating dam safety concerns

OPERATION AND MAINTENANCE (O&M)

An Operation and Maintenance (O&M) Program is a systematic means of ensuring that a dam is operated and maintained adequately. Adequate operation and maintenance is critical for ensuring . . .

- The continued safe operation of the dam.
- The continued productive use of the dam and reservoir.

In addition, an effective O&M Program can . . .

- Protect the environment by helping to preserve fish and wildlife habitats in the areas affected by the facility.

- Protect the investment made on the dam.

- Promote cost-efficient operation by avoiding some extraordinary maintenance that may otherwise occur if the dam were not properly maintained.

- Meet legal and social obligations.

An O&M Program includes the following major phases . . .

- **Planning.** During the planning phase, the O&M activities to be performed are identified, and the frequency of each O&M activity is determined.

- **Implementing.** During the implementation phase, the resource requirements for performing the O&M activities are identified, and the O&M activities are performed. Systems are established for monitoring and tracking O&M activities and expenditures. Finally, information is collected and records are maintained.

IV. DAM SAFETY PROGRAMS: CONDUCTING PROGRAM ACTIVITIES

OPERATION AND MAINTENANCE (O&M) (Continued)

- **Evaluating.** During the evaluation phase, the O&M Program is assessed. The costs, benefits, strengths, and weaknesses of the program are identified. The assessment information is used to plan new actions for improving the O&M Program.

Importance of an O&M Program

O&M helps to ensure dam safety. An effective O&M Program ensures that the dam will be operated and maintained according to design standards and established safety regulations. When a dam is operated and maintained according to standards and regulations, it is a safer dam.

O&M personnel can play an important role in the dam safety process. Because O&M personnel are frequently at the site, they are in a unique position to observe changing conditions at the dam site.

O&M personnel can inspect the dam and its appurtenances as part of their preventive maintenance tasks. Although these inspections are for O&M purposes, dam safety deficiencies may be observed. O&M personnel can contribute to dam safety by recording their observations and informing dam safety inspection personnel or other appropriate authorities of conditions that could indicate potential dam safety deficiencies.

Finally, some O&M personnel may have dam safety responsibilities in addition to their O&M responsibilities. O&M personnel may be responsible for conducting routine dam safety inspections. This type of dam safety inspection is often conducted on a set schedule or in conjunction with other routine O&M activities. A routine dam safety inspection is a visual inspection focusing on the current conditions of the dam and its features.

Components of an O&M Program

All dams--simple or complex, small or large--need to have established O&M Programs. The O&M Program should match the unique requirements of the dam site. There is a common misperception that if a dam is low hazard (i.e., poses no threat to life and minimal threat to property), then it need not be maintained. However, if the dam is of economic or social benefit, it behooves the dam owner to maintain the facility to ensure the continuation of those benefits. If the dam has no identifiable benefit, consideration should be given to removing it from service.

IV. DAM SAFETY PROGRAMS: CONDUCTING PROGRAM ACTIVITIES

Components of an O&M Program (Continued)

The components of an effective O&M Program are:

- **Specific O&M activities to be performed.**

  O&M activities will vary from one dam to another. To develop O&M activities, you must first assemble and review all pertinent information that is available about the dam. Reviewing this information will help provide a comprehensive description of the dam and its appurtenances and allow you to gain an understanding of the potential O&M needs. After you have a complete picture of the dam and its appurtenant structures and are familiar with the past and current conditions of the dam, you can identify the specific O&M tasks to be performed.

- **Operating procedures for the dam and reservoir.**

  Instructions should be developed for operating all equipment at the dam, for regulating the reservoir, and for the safe operation of the facility.

  Instructions for operable equipment must be based on the instructions provided by equipment manufacturers and the information contained in documents, such as the Designers' Operating Criteria (DOC). Instructions for operating the reservoir should provide for all reservoir operation contingencies and be accessible and easy to understand. General instructions should ensure the safe operation of the facility, and adequately protect the public and operating personnel.

- **Recordkeeping system.**

  A recordkeeping system should be implemented to record information about the dam's operation and maintenance, including . . .

  - O&M activities completed by O&M personnel.
  - Observations made by O&M personnel.
  - Scheduled and unscheduled maintenance.
  - Equipment, tools, and spare parts inventories.
  - Budget data.
  - Personnel records.
  - Visitor records.

IV. DAM SAFETY PROGRAMS: CONDUCTING PROGRAM ACTIVITIES

Components of an O&M Program (Continued)

- **Recordkeeping system** (Continued)

  This information can be used by O&M program managers to track the completion of specified O&M activities, and by dam safety inspectors to identify potential dam safety deficiencies and analyze trends developing in known deficiencies. Also, dam safety inspectors may not be able to observe the operation of mechanical equipment firsthand, and need to rely on operation records to gather information about some equipment.

- **O&M plan.**

  Once the O&M activities are identified and operating procedures and a recordkeeping system are developed, an O&M plan must be written to ensure that . . .

  - O&M tasks are performed based on an established schedule or on the results of routine O&M monitoring or inspection.
  - Approved operating procedures will be followed.
  - New operating personnel will be trained to follow approved procedures.
  - Authorized personnel can operate the dam and reservoir during emergencies when regular operating personnel may not be available.

The TADS module entitled How To Organize An Operation And Maintenance Program provides additional guidelines on planning, implementing, and evaluating an O&M Program.

EMERGENCY ACTION PLAN (EAP)

An Emergency Action Plan, or EAP, is a formal plan that identifies potential emergency conditions at a dam and prescribes the procedures to be followed to minimize property damage and loss of life.

An emergency in terms of dam operation is defined as a condition that develops unexpectedly, endangers the structural integrity of the dam and/or downstream property and human life, and requires immediate action.

☞ **NOTE:** Every EAP must be tailored to site-specific conditions and to the requirements of the agency/organization that owns or regulates the use of the dam.

IV. DAM SAFETY PROGRAMS: CONDUCTING PROGRAM ACTIVITIES

Importance of an EAP

An EAP is needed for two main reasons:

- To preplan the coordination of necessary actions by the dam owner and the responsible local, State, and/or Federal officials to provide for **timely** notification, warning, and evacuation in the event of an emergency.

- To reduce the risk of loss of life and property damage, particularly in downstream areas, resulting from an emergency situation.

The design, construction, operation and maintenance, and inspection of dams are all intended to minimize the risk of future dam failures. Despite the adequacy of these programs and their implementation, unique situations do sometimes develop that may result in dam failure. Therefore, it is prudent for dam owners to identify conditions that could lead to failure in order to initiate emergency measures that could prevent or minimize the consequences to life and property.

Components of an EAP

The components of an EAP are:

- **Notification Flowchart.**

  A Notification Flowchart is a schematic representation of the hierarchy for notification in an emergency situation, including who is to be notified, by whom, and in what priority. The flowchart should be prominently displayed in the EAP document; often it is the first page of the EAP.

- **Responsibilities.**

  Owners are responsible for the development and maintenance of the EAP, and for activating the notification procedures of the plan. Local, State, and Federal officials have statutory obligation and are responsible for warning and evacuation within affected areas. The EAP must specify the person(s) responsible for declaring an emergency under various circumstances, and for initiating emergency actions. In doing so, the plan must be site-specific, because conditions at all dams are different.

IV. DAM SAFETY PROGRAMS: CONDUCTING PROGRAM ACTIVITIES

Components of an EAP (Continued)

- **Emergency identification, evaluation, and classification.**

  Establishing procedures for reliable and **timely** recognition of emergency situations is imperative. If time permits, an emergency situation should be evaluated and confirmed by an experienced and qualified engineer. Finally, to determine the appropriate course of action, the emergency situation or triggering event should be classified according to its urgency.

- **Notification procedures.**

  Notification procedures should be developed to ensure the timely notification of persons responsible for taking emergency actions. The procedures should be brief, simple, and easy to implement.

- **Preventive action.**

  Preventive action is a general term used to refer to both preplanned and emergency actions that are aimed at preventing failure of a dam and minimizing loss of life and property damage. A few of the preventive actions that a dam owner might take are to ensure access to the dam site under adverse conditions, provide emergency flood operating instructions, and arrange for equipment, labor, and materials for use in emergency situations.

- **Inundation map.**

  An inundation map delineates the areas that would be flooded as a result of a dam failure or unusually large spillway releases. An inundation map is sometimes supplemented or replaced by a narrative description of the areas that would be flooded. Flood wave travel times to specified locations in the downstream floodplain should be given to enable the most effective evacuation planning.

- **Appendix(es).**

  One or more appendixes, containing supporting materials used in the development and maintenance of the plan, are usually included in the EAP document.

IV. DAM SAFETY PROGRAMS: CONDUCTING PROGRAM ACTIVITIES

DAM SAFETY INSPECTIONS

Dam safety inspections, along with subsequent investigations and analyses, are conducted to determine the status of a dam and its features relative to its structural and operational safety. Dam safety inspections are important in the early detection of deficiencies that could lead to major problems or even dam failure.

The range of activities performed during a dam safety inspection will vary depending on the type of inspection being conducted.

Dam safety inspection activities include the following:

- Reviewing project data
- Preparing a field inspection plan
- Conducting a dam safety inspection
- Documenting the results of a dam safety inspection

Types of Dam Safety Inspections

There are five types of dam safety inspections:

- **Initial or Formal Dam Safety Inspection.**

  Initial or formal dam safety inspections include an indepth review of all pertinent data available on the dam to be inspected. Design and construction data are evaluated relative to current criteria or current state-of-the-art in order to identify:

  - Potential dam safety problems that may not be apparent from a visual inspection.

  - Areas of the dam that may require particular attention during the inspection.

  After reviewing and evaluating the records, a thorough onsite inspection of all features is conducted. An attempt is made to operate all mechanical equipment through their full operating range, under as close to full design load (i.e., maximum reservoir elevation) as possible.

IV. DAM SAFETY PROGRAMS: CONDUCTING PROGRAM ACTIVITIES

Types of Dam Safety Inspections (Continued)

- **Periodic or Intermediate Dam Safety Inspection.**

  Periodic or intermediate dam safety inspections are conducted between formal inspections. A periodic or intermediate dam safety inspection differs from a formal inspection because while all available data are reviewed (in order to become thoroughly familiar with the dam and its features), they are not compared to the current state-of-the-art. The data review focuses on the current condition of the dam and its features.

  A comprehensive visual onsite inspection is conducted; however, all of the mechanical equipment may not be test-operated during any one inspection. An alternating schedule to test-operate equipment may be set up whereby certain equipment is tested during one inspection, and the remaining equipment is tested at another time or during the next scheduled inspection.

  For intermediate inspections, some agencies are willing to accept documentation of operation, such as an entry in a facility log describing when, and under what conditions, the different equipment had been tested or operated. If logs are used to document equipment operation, make sure the equipment was test-operated within the frequency and according to the conditions specified in the Standing Operating Procedures or the manufacturer's instructions.

- **Routine Dam Safety Inspection.**

  Routine dam safety inspections are typically conducted by field or operating personnel. The primary focus is on the current condition of the dam and its features. Data may not be reviewed and evaluated prior to this type of inspection, depending on the inspector's familiarity with the dam and its features.

  Routine dam safety inspections may be structured or unstructured. Structured routine inspections are conducted on a set schedule (e.g., weekly or monthly). Unstructured routine inspections are performed in conjunction with other routine tasks. For example, if a worker is at the toe of the dam to take a measurement from a weir, that worker may also inspect the entire toe and record any findings on a checklist or in a notebook.

IV. DAM SAFETY PROGRAMS: CONDUCTING PROGRAM ACTIVITIES

Types of Dam Safety Inspections (Continued)

- **Special Inspection.**

  A special inspection is conducted when only a particular feature of a dam is to be inspected. Often, a unique opportunity exists to inspect this feature which otherwise is not easily inspected. For example, if the reservoir has been lowered for maintenance reasons, an inspection of the upstream slope may be scheduled. Or, if divers are needed to inspect features generally under water, that inspection may be scheduled as a special inspection.

- **Emergency Inspection.**

  An emergency inspection is performed when the immediate safety of the dam is of concern, or in the event of unusual or potentially adverse conditions at the dam (e.g., during a large flood or immediately following an earthquake).

Reviewing Project Data

It is important to thoroughly review project data in preparation for a dam safety inspection in order to become as familiar as possible with the dam and its associated features. This information should be kept in a Dam Safety File for the dam.

When reviewing the Dam Safety File, special note should be made of past problems so that particular attention can be given to these during the site visit. In addition, for formal inspections, design and construction data are reviewed and evaluated relative to current practices and criteria in an effort to identify any inherent weaknesses in the dam. Any new data that becomes available during the inspection activity, or any changes in existing data, should be added to the Dam Safety File to keep it current.

Further information about reviewing project data may be found in the TADS module entitled Preparing To Conduct A Dam Safety Inspection.

Preparing a Field Inspection Plan

Preparation of a detailed field inspection plan will help ensure the thorough inspection of all project features, known problem areas, and areas of potential problems. In addition, a field inspection plan will help you identify and plan for special logistics, access, or equipment requirements.

Preparing a Field Inspection Plan (Continued)

An inspection plan is basically an extension of a site-specific checklist and the inspection objectives. The inspection plan should address the . . .

- Type of inspection to be performed.
- Order of the inspection.
- Equipment to be operated and the extent of operation planned.
- Special equipment needs or special arrangements (made in advance).

Steps taken to prepare a field inspection plan include:

- Developing an inspection outline or checklist.
- Developing inspection objectives.
- Making special arrangements.
- Making personal preparations.
- Addressing personal safety issues.

The inspection plan may be presented in the form of an inspection itinerary, and taken along on your inspection as a guide. It can be amended, if necessary, during the onsite inspection. Details on preparing a field inspection plan can be found in the TADS module entitled Preparing To Conduct A Dam Safety Inspection.

Conducting a Dam Safety Inspection

The manner in which an inspection proceeds will depend upon . . .

- Purpose of the inspection (type of inspection).
- Configuration of the facility.
- Operational considerations.
- Weather conditions.
- Obstructions or other restrictions to areas to be inspected.
- Personnel safety considerations.

If equipment is to be operated as part of the inspection, you should make arrangements for this in advance of the inspection. Reviewing reports from past inspections found in the Dam Safety File, and input from field representatives, will help you plan for inspecting and operating equipment and estimate the time needed for these activities.

Procedures and techniques for inspecting a dam and its appurtenant structures vary, depending on the type of dam. The TADS modules in the Inspection of Dams Component provide guidelines for conducting dam safety inspections.

IV. DAM SAFETY PROGRAMS: CONDUCTING PROGRAM ACTIVITIES

Documenting the Results of a Dam Safety Inspection

Accurate, complete, and concise documentation at the time of a dam safety inspection is essential to an inspector in later writing an inspection report. The most commonly used and accepted methods for recording an inspection include:

- Written or tape-recorded notes
- Visual records
  - Photographs
  - Videotapes
  - Annotated drawings and sketches

Written or Tape-Recorded Notes

The information typically recorded in written or tape-recorded notes includes:

✓ Inspection team participants.

✓ Weather conditions, especially rainfall amounts, immediately prior to (if known) and at the time of the inspection.

✓ Operating conditions such as reservoir and tailwater elevation, spillway and outlet works discharges, etc.

✓ Condition of all inspected features.

✓ Conditions under which equipment was operated.

✓ The location and description of any potential deficiencies.

✓ All quantitative measurements, including instrumentation readings and surveying results (if taken).

✓ Any personal safety hazards that could pose a threat to the public or project personnel.

Written or Tape-Recorded Notes (Continued)

✓ Description of changes in development of the upstream and downstream areas.

✓ Notations on any verbal information gathered, prior to or during the inspection, from operating personnel and other individuals who are not members of the inspection team.

☞ **NOTE:** Remember, there is no harm in having lots of notes. The problems occur when notes are either incomplete or inaccurate. You should record any and all information that you feel is important. Always be sure to note any unusual behavior or conditions, no matter how seemingly insignificant. Such notations may be the forewarning of a new or developing unsafe condition.

Checklists

Checklists may be used to facilitate taking notes or for actually documenting an inspection. The two common types of checklists used to document dam safety inspections are . . .

- **General Checklists.** General checklists provide broad coverage of the features "typical" for the type of dam being inspected. A general checklist can be used to assure coverage of all features of the dam. However, this type of checklist will not identify specific inspection objectives.

- **Site-Specific Checklists.** Site-specific checklists address the specific dam being inspected, and its particular features and concerns. A site-specific checklist may be created by modifying a general checklist. Site-specific checklists should be updated if the dam has been modified or rehabilitated.

Visual Records

Another method of notetaking is the use of visual records. This form of recordkeeping visually illustrates any features or phenomena that inspection team members observe during a dam safety inspection. The three types of visual records generally used during a dam safety inspection are:

- Photographs
- Videotapes
- Annotated drawings and sketches

Each of these three types of records can be a very effective means of recording information, and can be included as part of the inspection report.

IV. DAM SAFETY PROGRAMS: CONDUCTING PROGRAM ACTIVITIES

Additional Information

In some cases additional information, such as records and data, may be needed to supplement notes and visual records from a dam safety inspection. Records and data may be kept at the dam site. Obtain copies of any information that is pertinent to the inspection of the dam. Site records can be obtained by either requesting copies of the appropriate records, borrowing them, or by making copies and leaving the originals at the dam site.

Reviewing site records is an essential element of a proper and thorough dam safety inspection. Information contained in the site records should be reviewed and documented during the inspection because they may provide important information on instrumentation readings, maintenance, and operation.

Inspection Reports

The final stage of the inspection process is to develop a written inspection report. The written inspection report pulls together the information collected from the data review and the onsite inspection. In addition, the report presents the conclusions and recommendations that resulted from an evaluation of the information. The report becomes a part of the Dam Safety File and provides a permanent record of the conditions of the dam and recommended followup actions at a point in time.

The TADS module entitled Documenting And Reporting Findings From A Dam Safety Inspection provides additional information, including how to write an inspection report that is complete and accurate. This module also explains the inspection documentation process from the importance of background information to the necessity of maintaining a complete and updated Dam Safety File.

INVESTIGATIONS AND ANALYSES

Based on a review of data and the findings from a dam safety inspection, it may be necessary to conduct analyses to confirm the existence of suspected problems or to determine their seriousness. The analysis of a suspected problem may be performed in two phases.

A phase one analysis can be conducted using existing data and conservative assumptions. Phase one analysis might result in one of three alternatives. First, if a potential problem is found to be non-threatening, then no further analysis is needed.

Second, if a phase one analysis verifies that a problem does exist, then steps toward correcting the problem can be initiated.

IV. DAM SAFETY PROGRAMS: CONDUCTING PROGRAM ACTIVITIES

INVESTIGATIONS AND ANALYSES (Continued)

Third, if a phase one analysis is inconclusive, as often happens, then further studies must be undertaken.

Investigations, including field exploration, sampling, and laboratory testing of materials may be performed to determine the actual site conditions and material properties. These actual conditions and data are then used in a more sophisticated phase two analysis to confirm whether a problem does exist and, if so, to define the severity and extent of the problem.

CORRECTING OR MITIGATING DAM SAFETY CONCERNS

After gathering data during an onsite dam safety inspection, inspectors compare observations and findings made during routine dam safety inspections by employees who work at the site, with structural behavior (instrumentation) and other technical data and prior inspection reports. During this process, the causes or consequences of deficiencies may be defined, or further study may be necessary.

Evaluating the Safety of a Dam

When evaluating the results of the inspection and analysis efforts, the need for taking corrective action on a dam or its appurtenances may emerge. Two types of deficiencies can trigger a recommendation for corrective action:

- **Condition deficiencies**, such as cracks, misalignment, uncontrolled seepage, etc. Such deficiencies are detected by visual observation or review of instrumentation and other performance data.

- **Design or construction deficiencies**, such as inadequate spillway capacity due to a revised design flood or outdated design or construction methods, are detected by reviewing design and construction data and comparing them with the current state-of-the-art and practice.

Evaluating the Operation and Maintenance Plan

Inspectors should review the operation and maintenance plan during the inspection to determine if the plan needs revision to meet safety concerns.

IV. DAM SAFETY PROGRAMS: CONDUCTING PROGRAM ACTIVITIES

Evaluating the Emergency Action Plan: Regulators

The Emergency Action Plan should be evaluated as part of the inspection program. The written plan needs to be examined to assure that it is current and complete. Factors such as communication systems, auxiliary power equipment, and access to the site also must be considered, because these elements are vital to the plan's workability. Periodic testing of the plan should be required.

CORRECTING DEFICIENCIES

Dam owners must take corrective action when deficiencies are found that threaten a dam's safety.

Determining the Need for Corrective Action

The need for corrective action is established by:

- Direction from a regulatory agency
- Recommendations from in-house engineers
- Recommendations of consulting engineers

Examples of reasons for recommending corrective action include:

- Structural deficiencies.

- Changes in engineering criteria, such as new methods for computing dynamic stability, updated hydrologic data, or advancements in the state-of-the-art understanding of dam performance that call into question a dam's continued safe performance.

Recommending Corrective Action

Before recommending that a potential dam safety deficiency be corrected, the following steps must usually be completed:

- Investigate to verify the existence of a deficiency

- Determine the severity of the deficiency

Inspection findings concerning condition affect a dam's priority for modification or repair. Priorities for modification or repair also change in response to updates in hazard classifications.

IV. DAM SAFETY PROGRAMS: CONDUCTING PROGRAM ACTIVITIES

Recommending Corrective Action (Continued)

If staff engineers lack the specialized knowledge to recommend corrective measures, consultants may be used.

Dam owners need to be advised about the available options to correct a dam safety deficiency.

Evaluating Alternative Actions

There are usually a number of possible actions that will correct a deficiency. Alternatives include . . .

- Making structural corrections
  - Constructing new structures, such as an emergency spillway
  - Modifying existing structures, such as raising the crest of the dam
  - Making extensive repairs to existing structures
- Taking nonstructural corrective action
  - Implementing operating restrictions, such as a lower reservoir elevation
  - Installing an early warning system

Nonstructural measures should be considered fully when selecting corrective actions. If structural corrections are necessary, nonstructural measures may also be used in combination to reduce total costs.

Consider the following points when choosing an alternative:

- **Cost.** Consulting or staff engineers can identify alternative actions, and conduct preliminary cost studies to determine cost associated with each alternative.
- **Impact.** Environmental, political, social, and economic impacts are factors in many decisions.
- **Risks.** Risk analysis compares the monetary cost of making a particular modification to the risk in lives and property of a failure that might result from taking no action. A continuum of alternatives with increasing costs and decreasing risks is evaluated during this procedure.

IV. DAM SAFETY PROGRAMS: CONDUCTING PROGRAM ACTIVITIES

Evaluating Alternative Actions (Continued)

Decision analysis weighs all of the alternative actions being considered and assigns numerical values to each alternative. Such analyses can be complex and expensive due to the many scenarios that must be evaluated. In some instances, an owner may forego decision analysis and instead devote funds toward the cost of a specific modification or repair.

During the decision-making process, regulatory officials usually must be contacted for approval.

Making Structural Corrections

Reasons for making structural corrections include:

- Repair or replacement of damaged or deteriorated components (for example, lining a badly rusted outlet works conduit).
- Modifying the structure to make it meet revised engineering criteria (for example, by increasing spillway capacity or increasing the freeboard).
- Upgrading the structure to meet standards for a higher hazard classification caused by new downstream development (for example, by increasing the capability to safely pass larger floods).

Taking Nonstructural Corrective Actions

In some instances, nonstructural corrective actions may be taken to remedy a problem. Most nonstructural corrective actions are solutions that require minimal funding, but could result in environmental damage or lost benefits from the reservoir. Examples of nonstructural corrections include:

- Breaching the dam so that it will not impound water.
- Establishing a reservoir restriction that will alleviate the deficiency.
- Establishing flood forecasting systems.
- Restricting development in the flood plain.

IV. DAM SAFETY PROGRAMS: CONDUCTING PROGRAM ACTIVITIES

Taking Nonstructural Corrective Actions (Continued)

- Installing automatic early warning systems.
- Removing homes or other development downstream from the dam to reduce the hazard classification. (In many cases, this solution would be far less expensive than modifying or repairing the dam.)

Relying on warning systems involves some element of risk, because there is no guarantee that all affected persons will be warned and respond in time to reach safety. Therefore, regulatory agencies are likely to scrutinize this type of action and impose strict limitations.

Specific Corrective Actions

There are numerous other corrective actions that can be taken to remedy specific deficiencies. Corrective actions for specific dam safety deficiencies can be found in other TADS modules.

APPENDIX A

GLOSSARY

GLOSSARY

ABUTMENTS - Those portions of the valley sides which underlie and support the dam structure, and are usually also considered to include the valley sides immediately upstream and downstream from the dam.

APPURTENANT STRUCTURES - Auxiliary features of a dam that are necessary to the operation of the dam project. These may include spillways, outlet works, gates and valves, power plants, tunnels, and switchyards.

AUXILIARY (EMERGENCY) SPILLWAY - A secondary spillway that passes floodwater during rare, severe floods, and may be expected to need extensive repair after such events.

BREACH - An eroded opening through a dam that drains the reservoir. A controlled breach is a construction opening. An uncontrolled breach is an unintentional opening that allows uncontrolled discharge from the reservoir.

CONDUIT - A pipe or box structure constructed by joining sections of pipe or conduit in an excavated trench, inside a tunnel, on the ground surface, or supported on cradles.

CREST - The top surface of the dam or high point of the spillway control section.

DAM - A barrier constructed across a watercourse for the purpose of storage, control, or diversion of water.

DAM FAILURE - The uncontrolled release of impounded water. There are varying degrees of failure.

DAM SAFETY FILE - A compilation of all information pertinent to the safety of a specific dam. A separate Dam Safety File may exist; however, some organizations consider a compilation of existing project files to be the Dam Safety File.

DEFICIENCY - An anomaly or condition that affects or interferes with the proper and safe operation of the dam.

DOWNSTREAM FACE - The inclined surface of a concrete dam that faces away from the reservoir.

DOWNSTREAM SLOPE - The inclined surface of an embankment dam that faces away from the reservoir.

EMBANKMENT DAM - Any dam constructed of excavated natural materials (includes both earthfill and rockfill dams).

GLOSSARY

EMERGENCY - A condition which develops unexpectedly, endangers the structural integrity of a dam and/or downstream property and human life, and requires immediate action.

EMERGENCY ACTION PLAN (EAP) - A formal plan of procedures designed to minimize consequences to life and property, and requires immediate action.

EMERGENCY SPILLWAY - See **AUXILIARY SPILLWAY**.

EROSION - The wearing away of the earth's surface, as by floods, glaciers, waves, wind, or any other natural process.

FAILURE - The catastrophic breakdown of a dam, characterized by the sudden, rapid, and uncontrolled release of impounded water.

FLASHBOARDS - Individual boards or panels supported by vertical pins or stanchions anchored to the spillway crest to increase storage.

FLOOD - A temporary rise in water levels resulting in inundation of areas not normally covered by water. Hypothetical floods may be expressed in terms of probability of exceedance per year such as one percent chance flood, or expressed as a fraction of the probable maximum flood or other reference flood.

FOUNDATION - The portion of the valley floor that underlies and supports the dam structure.

FREEBOARD - The vertical distance between a stated water level and the top of a dam or spillway crest.

GATE - An adjustable device used to control or stop the flow of water in a waterway. A gate consists of a leaf or member which is moved across the waterway from an external position.

HAZARD CLASSIFICATION - A rating (e.g., low, moderate/significant, or high hazard) that is a representation of the probable loss of life and property damage downstream from a dam based on the results of breaching studies of the dam, and an identification of the area downstream that would be inundated.

HEEL - The junction of the upstream face of a concrete dam with the ground surface.

INSTRUMENTATION - An arrangement of devices installed into or near dams (e.g., piezometers, inclinometers, strain gages, measurement points, etc.) that provide measurements used to evaluate the structural behavior and performance of the structure.

GLOSSARY

INTAKE STRUCTURE - Placed at the beginning of an outlet works waterway, the intake structure establishes the ultimate drawdown level of the reservoir by the position of its opening(s) to the outlet works. Intake structures may be vertical or inclined towers, drop inlets, or submerged, box-shaped structures. Intake elevations are determined by the head needed for discharge capacity, storage reservation to allow for siltation, the required amount and rate of withdrawal, and the desired extreme drawdown level.

INTERNAL EROSION - See **PIPING**.

LEAKAGE - The undesirable flow of water through joints, cracks, and openings in hydraulic structures.

OUTLET - An opening through which water can be discharged.

OUTLET WORKS - A system of dam components that regulates or releases water impounded by a dam. Components of an outlet works include an entrance channel, intake structure, conduit, gate or valve housing, energy dissipators, and return channel.

PENSTOCK - A pipeline or pressure conduit leading from a headrace or reservoir to power-producing turbines. Because of the possibility of sudden load changes, a penstock is designed to withstand pressure surges.

PIPING - The progressive internal erosion of embankment, foundation, or abutment material.

PROBABLE MAXIMUM FLOOD (PMF) - The flood that may be expected from the most severe combination of critical meteorologic and hydrologic conditions that are reasonably possible in the drainage basin under study.

RESERVOIR - The body of water impounded by a dam.

RESERVOIR RIM - The boundary of the reservoir including all areas along the valley sides above and below the water surface.

SEEPAGE - The passage of water through embankment, foundation, or abutment material.

SHOULDERS - The upstream and downstream edges of the crest of the dam.

SOLUTIONING - A chemical dissolving of minerals present in soil or rock.

GLOSSARY

SPILLWAY - A structure over or through which flood flows are discharged. If the rate of flow is controlled by mechanical means, such as gates, it is considered a controlled spillway. If the elevation of the spillway crest is the only control, it is considered an uncontrolled spillway.

STANDING OPERATING PROCEDURES (SOP) - Written guidelines to be followed for normal and emergency operation of the components of a dam.

STILLING/HYDRAULIC JUMP BASIN - A structure designed to produce a hydraulic jump that will dissipate energy.

TOE OF DAM - The junction of the downstream slope of a dam with the ground surface; also referred to as the **downstream toe**. For an embankment dam, the junction of the upstream face with the ground surface is called the **upstream toe**.

UPSTREAM FACE - The vertical or near-vertical surface of a concrete dam that is in contact with the reservoir.

UPSTREAM SLOPE - The inclined surface of an embankment dam that is in contact with the reservoir.

VALVE - An adjustable device used to control or stop the flow of water in a waterway. A valve is fixed permanently within the waterway, and has a closure member that is either rotated or moved transversely or longitudinally in the waterway in order to control or stop the flow.

WATER CONVEYANCE STRUCTURE - A non-specific reference to either a spillway, an outlet works, or penstock.

APPENDIX B

REFERENCES

REFERENCES

Advanced Dam Engineering for Design, Construction, and Rehabilitation. Robert B. Jansen, editor. Van Nostrand Reinhold, New York, New York, 1988.

Dams and Public Safety. Robert B. Jansen. A Water Resources Technical Publication, U.S. Department of the Interior, Water and Power Resources Service, Denver, Colorado, 1980.

Dam Safety: An Owner's Guidance Manual. Federal Emergency Management Agency, FEMA 145, August, 1987.

Dam Safety Guidebook. STS Consultants, Ltd., 1985.

Legal Liability for Dam Failures. Denis Binder, Association of State Dam Safety Officials, 1989.

Lessons From Dam Incidents, USA. United States Committee on Large Dams, American Society of Civil Engineers, New York, New York, 1975.

National Dam Safety Program--A Progress Report. Federal Emergency Management Agency, FEMA 195, Volume 1, July 1990.

Safety of Existing Dams--Evaluation and Improvement. Committee on the Safety of Existing Dams, National Research Council, National Academy Press, Washington, D.C., 1983.

U.S. GOVERNMENT PRINTING OFFICE: 1994—840-954