



Guidelines for Safety Inspection of Dams

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Central Water Commission
Ministry of Water Resources,
River Development & Ganga Rejuvenation
Government of India

Front Cover Photograph: Dam safety inspection team at Hidkal Dam constructed across the Ghataprabha River at Hukkeri in Belgaum District in the State of Karnataka.

Dam Safety Rehabilitation Directorate
Central Dam Safety Organization
Central Water Commission
3rd Floor, New Library Building (Near Sewa Bhawan)
R. K. Puram, New Delhi – 110066.
Email: dir-drip-cwc@nic.in



Government of India
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3rd Floor, New Library Building
R. K. Puram
New Delhi – 110066



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Guidelines for Safety Inspection of Dams was first published in 2001. This comprehensive revision is one in a series of several dam safety guidelines being developed under the Dam Rehabilitation and Improvement Project (DRIP).

Disclaimer

Safety inspection of existing dams are conducted at periodic intervals, usually pre-monsoon and post-monsoon, and after any extreme event such as a large flood or an earthquake. The methods and requirements vary for the several types of dams and for routine periodic inspections and post-event inspections. The Central Water Commission (CWC) is coordinating the implementation of Dam Rehabilitation and Improvement Project (DRIP), and as part of institutional strengthening component of DRIP, guidelines, and manuals are prepared to cover different aspects of dam design, operation, maintenance, and rehabilitation. Every effort was taken to specify the methods and requirements for safety inspection of the several types of dams and their appurtenant works.

Several uncertainties associated with the inspection and there could be variations in the implementation of the guidelines. CWC cannot guarantee the efficacy of these inspections and absolves itself from any responsibility in this regard.

For any information, please contact:

The Director
Dam Safety Rehabilitation Directorate
Central Dam Safety Organization
Central Water Commission
3rd Floor, New Library Building (Near Sewa Bhawan)
R. K. Puram, New Delhi – 110066.
Email: dir-drip-cwc@nic.in

FOREWORD

Eighty percent of more than 5000 large dams in India are greater than 25 years old, and their health and safety are of paramount importance for sustainable use of these valuable assets, besides protecting people, property, and the environment. Safety inspections of the dams are carried out at periodic intervals pre-monsoon and post-monsoon and after any extreme event – such as a flood or an earthquake – and actions are taken to ensure the safety of the dams. The Central Water Commission (CWC) published guidelines for safety inspection of dams in June 1987. However, there was a need to revise these guidelines to consider the technological developments since then and the experience gained from the dam safety inspections carried out over the period.

The CWC is coordinating the implementation of the Dam Rehabilitation and Improvement Project (DRIP), undertaken with the financial assistance from the World Bank, to rehabilitate about 250 large dams in seven States. As part of institutional capacity building component of DRIP, CWC took the initiative to prepare new guidelines and revise existing guidelines as necessary. The revised guidelines for safety inspection of dams address comprehensively the dam safety inspection programme, procedures, special inspection techniques, and requirements for inspection of embankment dams, concrete and masonry dams, composite dams and the appurtenances like spillways and outlets. The guidelines also consider the preparatory steps to be taken before planning the inspections, including selection of inspection team and collection of needed documentation. Inspection checklists presented in the guidelines should be reviewed and customized for different inspections. They should aid the inspection and should not become a restriction. Inspection report forms provided with these guidelines help in standardizing the same for uploading onto the Dam Health and Rehabilitation Monitoring Application (DHARMA), the online tool being developed for maintaining the asset and health data of all large dams in India. Hints for writing an inspection report help in consistency of the inspection reports.

Use of remotely operated underwater vehicles (ROVs) for upstream underwater inspection of dam body and the reservoir floor and the unmanned aerial vehicles (UAVs) also called DRONES for surface mapping of the downstream face of the dam and the catchment area are increasingly being used in developed countries. Brief information about these advanced techniques also included in the guidelines.

The Guidelines is being published on DRIP (www.damsafety.in) and CWC (www.cwc.gov.in) websites and free access is provided to all. Personnel concerned with dam safety inspections are encouraged to implement the guidelines.

15 June 2017
New Delhi

(Narendra Kumar)
Chairman
Central Water Commission

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PREFACE

The Central Water Commission is initiating, coordinating and furthering the schemes for control, conservation, and utilization of water resources throughout the country. As part of its institutional strengthening initiatives, CWC published several guidelines and manuals on several topics associated with design, construction, operation, maintenance and rehabilitation of dams. CWC is coordinating the implementation of Dam Rehabilitation and Improvement Project (DRIP) with financial assistance from the World Bank. CWC took up the revision of two of the existing guidelines and development of 11 new guidelines along with three dam design review manuals under the aegis DRIP.

In revising the guidelines for safety inspection of dams published in June 1987, CWC used the experience gained, and the technological developments over the years. Best practices adopted across the world and experience were also considered in revising the guidelines. Dam Health and Rehabilitation Monitoring Application (DHARMA), the online tool for capturing asset and health data of all the large dams in India is being developed under DRIP. Standardization of inspection reporting formats helps in uploading the inspection reports and for the analysis of the outcomes.

The revised guidelines comprehensively cover all the types dam safety inspections specific to different types of dams like embankment dams, concrete and masonry dams, composite dams and the appurtenances such as spillways and outlets. There are more than 5000 large dams in the country, and the detail and frequency of inspections carried out by State Agencies may be at variance. Consolidation of the inspection results and their analysis to develop policy initiatives for sustainable dam safety become difficult. Implementation of these guidelines will improve the efficacy of these inspections and provide consistency in report writing and facilitate their analysis. Users may freely download these guidelines from DRIP (www.damsafety.in) and CWC (www.cwc.gov.in) websites.

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LIST OF ACRONYMS

The following acronyms are used in this publication:	
AAR	Alkali-Aggregate Reaction
ASTM	American Society for Testing Materials
CDSO	Central Dam Safety Organization
CWC	Central Water Commission
DDMA	District Disaster Management Authority
DHARMA	Dam Health and Rehabilitation Monitoring Application
DRIP	Dam Rehabilitation and Improvement Project
DTM	Digital Terrain Model
EAP	Emergency Action Plan
FSCT	Federation of Societies for Coatings Technology
LIDAR	Light Detection and Ranging
NCDS	National Committee on Dam Safety
PAR	Population at Risk
PMF	Probable Maximum Flood
PMP	Probable Maximum Precipitation
RCC	Roller Compacted Concrete
ROUV	Remotely Operated Underwater Vehicle
ROV	Remotely Operated Vehicle
SDSO	State Dam Safety Organization
UAV	Unmanned Aerial Vehicle
USBR	U.S. Bureau of Reclamation
USACE	U.S. Army Corps of Engineers

Chapter 1. OVERVIEW OF DAM INSPECTION

The primary aim of these *Guidelines for Safety Inspection of Dams* is to give dam owners, dam engineers, and other professionals with information to help guide the planning and execution of dam inspection programs. This document builds upon earlier guidelines for the safety inspection of dams developed by the Central Dam Safety Organization (CDSO) of the Central Water Commission (CWC) (CDSO 1987 and 1988) and the Bureau of Indian Standards (BIS 2001).

The objectives of dam safety inspections are to:

- ensure the dam system will perform as expected,
- identify deficiencies or areas that need monitoring or immediate repair,
- assess the soundness of the dam and record any changes that have occurred,
- collect information to make informed decisions about needed remedial measures, and
- find out if the dam is being operated and maintained properly.

This guideline recommends procedures for completing and documenting a dam inspection. The term “inspection,” as used here, includes the entire evaluation process, consisting of a project file or data review, an on-site examination (visual inspection), and report preparation. The principles, concepts, and procedures will be readily adaptable to any organization that inspects dams and evaluates their compliance with current design standards. The several types of inspections are discussed in Chapter 2.

A dam safety inspection program is essential to the long-term stability and safety of a dam and should be part of every dam operation plan. The purpose of the examination is to evaluate the structural and operational aspects of the dam, to detect and resolve prob-

lems, and to verify that the parts are functioning properly. An effective inspection program helps protect the downstream interests and reduces the dam owner’s risk of financial and legal liabilities that would result from a dam failure. The inspections should be scheduled and performed on a regular basis. Inspection and maintenance of dams are critical to their long-term performance. However, it should be stressed that inspections alone do not make dams safe; prompt repairs and maintenance are essential to the safe operation of every dam.

People who carry out dam inspections need to know about dam design, construction, and operation to evaluate the dam conditions properly. An inspector should be a qualified dam safety professional with experience in the technical issues met at a dam. For instance, an inspector must have knowledge of structural engineering if the dam has a significant concrete spillway structure, or knowledge of geotechnical engineering if the dam has an earth embankment. This is especially important if the structures have known problems that need evaluation and repair. The importance of proper inspector training and experience cannot be overemphasized. The recommended members and competencies of a qualified inspection team are discussed in Chapter 3.

Inspectors must report dam conditions accurately and thoroughly to protect the dam owner’s interests and to reduce potential liabilities as much as possible. Inspectors may be held liable and accountable for dam failures resulting from unreported or understated conditions and problems. It is important for inspectors to document any limitations of their inspection. For example, deficiencies or problems may not be readily detectable at some dams if excessive vegetation is present, if access to certain features is not possible, or if there are problems within the embankment or under a structure that cannot be seen.

It is also important that all inspectors develop an unbiased approach to inspections and provide a complete and accurate reporting of existing conditions. If an inspector changes the safety rating of the dam or one of its components from prior ratings, substantive documentation needs to be prepared to support the change.

The CDSO now classifies dams into one of three categories based on the hazards they present to life and property. A hazard classification is a rating (e.g., low, significant, or high hazard) that is representative of the probable loss of life and property damage that would occur downstream from a dam in case of a failure resulting in breaching and an uncontrolled release of water from the reservoir. The following definitions of hazard classification now apply to dams in India:

- 1) High hazard dam: a dam whose failure would cause the loss of life and severe damage to homes, industrial and commercial buildings, public utilities, major highways, or railroads.
- 2) Significant hazard dam: a dam whose failure would damage isolated homes and highways, or cause the temporary interruption of public utility services.
- 3) Low hazard dam: a dam whose failure would damage farm buildings, agricultural land, or local roads.

This document offers guidance for performing safety inspections for all three classes of dams. Dam owners should refer to current CDSO regulations to review the specific inspection, reporting, and inspector training requirements for their dams. Chapters 4 through 8 give a quick reference to be used in assessing observed conditions, their probable cause, and consequences and remedial actions that may solve the observed problems or deficiencies. The dam owner/operator can use the results of inspections to detect changes in previously noted conditions that may forewarn of an impending safety concern. Quick corrective action to conditions needing attention will extend the useful life of the dam, prevent costly future repairs, and reduce the risk

presented by the dam. Chapter 9. describes how to document inspection findings.

1.1 Why are Dam Safety Inspections Needed?

The primary goal of the Central Dam Safety Organization of the Central Water Commission is to encourage and assist the advancement of dam safety practices that will help ensure operation of dams to their full capacities and intended purposes, and also to reduce the risk to lives and property from the consequences of both structural and operational dam incidents and failures.

Although most dam owners have an elevated level of confidence in the structures they own and are confident their dams will not fail, history has shown that on occasion dams do fail and that often these failures cause extensive damage to property, and sometimes loss of life. Dam owners are responsible for keeping these threats to acceptable levels. The dam owner shall ensure availability of adequate funds for regular scheduled inspection and maintenance of dams and appurtenant structures.

To reduce the risk of dam failure, regular inspections, effective instrumentation, and diligent monitoring are needed to identify potential problems and take corrective actions to remedy those deficiencies before serious consequences develop. Construction deficiencies, earthquakes, and large floods are some of the reasons for dam deterioration that could lead to failure, but ageing and inadequate maintenance are the main causes. The processes of deterioration, design practices that would help avoid those problems, and the methods that might be used to control or prevent the ongoing effects of ageing are described in *DRIP Information Bulletin No. 5 – India's Ageing Large Dams – Lessons from DRIP* (CDSO 2016c)

The need for dam safety inspections is emphasized in the draft *Dam Safety Bill, 2016* which was circulated to all the States and Union Territories on August 09, 2016. Furthermore, the draft Dam Safety Bill was discussed during the 37th meeting of the National Committee on Dam Safety (NCDS) held on

February 17 and 18, 2017. Following the comments received from various States and the outcome of the NCDS deliberations, some changes in the Bill were suggested, and the matter was referred to the Ministry of Law and Justice. The draft Dam Safety Bill seeks to “provide for surveillance, inspection, operation and maintenance of specified dams and to provide for an institutional mechanism to ensure their safe functioning and for matters connected therewith or incidental thereto.”

Clause 15 of the Bill (Surveillance and Inspection) specifies that every State Dam Safety Organization (SDSO) shall:

- a) keep perpetual surveillance,
- b) carry out inspections, and
- c) monitor the operation and maintenance, of all specified dams falling under their authority to ensure continued safety of such specified dams and take such measures as may be necessary to consider safety concerns with a view to achieving a satisfactory level of assurance as per the guidelines, standards and other directions on dam safety.

Clause 30 of the Bill requires that every owner of a specified dam shall undertake every year, through their dam safety unit, a pre-monsoon and post-monsoon inspection of such dams. Also, the owners shall inspect or cause to be inspected every dam by the dam safety unit, during and after every flood, earthquake or any other natural or artificial calamities, and if any sign of distress or unusual behavior is noticed in the dam, appurtenance or reservoir rim.

1.2 Publication and Contact Information

This document along with the dam safety inspection report template is available on the CWC website

<http://www.cwc.gov.in>

and the Dam Rehabilitation and Improvement Project (DRIP) website (DRIP 2017a)

<http://www.damsafety.in>

For any further information contact:

The Director
 Dam Safety Rehabilitation Directorate
 Central Dam Safety Organization
 Central Water Commission
 3rd Floor, New Library Building
 R. K. Puram, New Delhi – 110066
 Email: dir-drip-cwc@nic.in

1.3 Acknowledgments

In preparing these guidelines, work of others in India, the United States, and elsewhere has been drawn from liberally. Grateful appreciation is extended to the following organizations whose publications and websites are sources of valuable information on dam safety inspections:

- Association of Sate Dam Safety Officials (United Sates)
- Federal Emergency Management Agency, U.S. Department of Homeland Security
- International Commission on Large Dams
- U.S. Army Corps of Engineers
- U.S. Bureau of Reclamation
- Indiana Department of Natural Resources, Division of Water
- Texas Department on Environmental Quality, Dam Safety Program

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Chapter 2. DAM SAFETY INSPECTION PROGRAM

The primary purpose of the dam safety inspection program is to enhance the security of dams and appurtenant structures for the protection of downstream life and property. Dam safety inspections are made to ensure proper operation and maintenance; to discover unsafe conditions and determine why they exist; to recommend remedial measures that safeguard the structure and appurtenances, and to confirm that the dam meets the minimum State Dam Safety Organization or State Dam Safety Cell requirements.

2.1 Overview of Dam Types

There are many types of dams. Some—such as timber dams and steel dams—are outdated and no longer considered practical, and will not be approved. Following is a brief overview of the most common dam types that are now being built.

2.1.1 Embankment Dams

Embankment dams include earthfill and rockfill dams. Embankment dams:

- Are the most common (and often most economical) type of dam.
- Utilize materials, usually available locally that do not require a high degree of processing.
- Have requirements for an adequate foundation that are not as extensive or critical as those for most other dam types.
- Have more potential sites available, especially in Texas.
- Are more susceptible to erosion.
- Require continuous maintenance (including substantial vegetation control).

2.1.2 Concrete and Masonry Dams

Concrete dams include gravity, arch, buttress, and roller-compacted concrete (RCC) dams. Concrete dams:

- Are best suited for in-channel overflow structures, as well as narrow gorges.
- Are less susceptible to erosion.
- Rely on the weight of the structure and/or the strength of the bond or anchor at the abutments.
- Require solid impervious strata for an adequate foundation (an extensive geotechnical investigation is critical).

2.1.3 Composite Dams

Composite dams use an earthfill or rockfill embankment for the non-overflow portion of the dam and concrete or masonry for the overflow spillways and/or special structures such as hydroelectric power plants and navigation locks. Embankment dams with incidental concrete structures (such as conduits, chutes, aprons, retaining walls, slabs, footings, and splash pads) are not typically considered to be composite dams.

2.2 Inspection Elements

Every inspection should consist of three to five elements, depending on the type of inspection. All inspections should include the first three of following items, while comprehensive evaluation inspections should also include the last two:

- 1) File review
- 2) Visual inspection (field examination)
- 3) Report preparation
- 4) Owner education
- 5) Report submittal (to CDSO)

It should be noted that the visual inspection is just one component of the dam inspection process and that a dam safety inspection refers to the entire inspection process including the five elements described above.

The dam safety inspection program for every dam should begin with an initial, comprehensive evaluation inspection. First, an

assessment of the background, design, construction, and performance history of the dam is conducted using available files and data. Second, a thorough visual inspection of the entire facility is made to assess and document current conditions. Then, the stability and soundness of the dam are evaluated with conclusions and recommendations for repairs or improvements. Additional field, laboratory, and analytical studies may be required if adequate information is not available. The findings, conclusions, and recommendations should be documented in an inspection report, as discussed in Chapter 9.

All dams may require additional comprehensive evaluation inspections on a regular basis for as long as the dam exists, depending on hazard classification and current CDSO regulations. The amount of background information needed, the frequency of the inspections and the reporting procedures are dependent on the hazard classification, the size and type of dam, and current CDSO regulations. For example, high hazard dams that pose a significant risk to downstream property require more detailed background information and more frequent and rigorous inspections than low hazard dams with small reservoirs. The level of inspection effort should correspond to the hazard potential of the dam.

After the initial, comprehensive evaluation inspection and any required remedial measures have been completed, dam safety inspections should continue to be performed to monitor and detect any unfavorable changes that might develop in the condition of the dam that would adversely affect safety. Subsequent inspections by the same personnel may not require as detailed a review of the background, design, construction, and performance history of the dam as would be needed if a completely new inspector team was formed. However, the inspection program should continue to consider the same basic issues that were dealt with in the initial comprehensive evaluation inspection. The continuing dam safety inspections include more comprehensive evaluation inspections

for high hazard dams, and maintenance, informal, and special inspections for all dams.

A scheduled inspection is a preventive measure designed to find problems and to develop solutions to prevent further degradation of the dam. scheduled inspections involve reviewing past inspection reports, performing a visual inspection, and completing a report form. scheduled inspections are usually carried out by a qualified inspection team along with maintenance staff or the dam owner.

For informal inspections, the evaluation process typically consists of a review of file data such as reports, photographs, or monitoring data, visual inspection, and completion of a report form or inspection brief. An informal inspection can be conducted at any time and may include only portions of the dam or its appurtenant structures. Informal inspections are usually conducted by project personnel or dam owners as they operate the dam to monitor known problem areas or to provide an update on site conditions between maintenance and comprehensive evaluation inspections.

Special inspections should be performed when potentially dangerous events occur (an extreme flood or seismic event, for example), when the upstream or downstream watershed conditions change (new development, for instance), when newly developed, more realistic methods of analysis become available, or as a follow-up to a formal technical or scheduled inspection to deal with a specific issue.

A complete inspection report or inspection brief should be prepared every time an inspection is performed. A full report should be prepared for comprehensive evaluation inspections; an inspection report form (see the Scheduled Dam Safety Inspection Form in Appendix B) or inspection brief may be used for all other types of inspections. The inspection report or brief should document the observations made in the field, present any instrumentation or other performance data trends since the last report, present conclusions on the dam's apparent adequacy, and

present any necessary recommendations. An inspection brief is an informal report that consists of a log entry in a book or on a sheet of paper denoting observed conditions, with conclusions, recommendations, or other notes as may be deemed appropriate. If at any time, inspectors notice any adverse trends, they should communicate them at once to the owner of the dam. Dam owners should refer to current CDSO regulations to determine agency reporting requirements for their dams.

The overall dam safety inspection program is a continuing process of evaluating a dam's performance based on review and analysis of performance records and field observations. A dam safety inspection performed on a regular basis is one of the most economical means a dam owner can use to assure security and long life of a dam and its immediate environment. The visual inspection, a component of all types of inspections, is a straightforward procedure that can be performed by any properly trained person to make a reasonably accurate assessment of a dam's condition. The visual inspection component involves careful examination of the surface and all parts of the structure, including its adjacent environment. The equipment required is not expensive, and the visual inspection component usually can be completed in less than one day. The entire inspection process will usually take longer to complete than one day, depending on the type of inspection and the complexity of the dam.

A dam, even though previously found safe by analysis and demonstrated performance, cannot be considered safe forever. Continued vigilance, visually and analytically, is essential. The integrity of the dam must be reevaluated whenever the embankment or discharge structures are damaged, and when upstream or downstream watershed conditions are significantly altered.

2.3 Types of Inspections

Four types of dam safety inspections are carried out for all dams, regardless of their hazard classification:

- 1) Comprehensive evaluation inspections

- 2) Scheduled inspections
- 3) Special (unscheduled) inspections
- 4) Informal inspections

The frequency of each type of inspection should depend on the hazard classification of the dam, the condition of the dam, and current CDSO regulations.

2.3.1 Comprehensive Evaluation Inspections

A comprehensive evaluation inspection of a dam typically consists of five components:

- 1) File review (or compilation of an information database if it is the first comprehensive evaluation inspection, or if files do not exist or are inadequate).
- 2) Visual inspection, or field examination of the dam and its appurtenant works.
- 3) Preparation of a detailed report of the inspection.
- 4) Education and training of the dam owner on the results of the dam inspection and other issues relating to dam safety, including potential dam failure modes. Dam owners should be made part of the examination process so that they take ownership of the results and are committed to implementing recommended remedial measures.
- 5) Submittal of the report to the SDSO if so required under current CWC regulations.

This subchapter describes the requirements for conducting a comprehensive evaluation inspection. Subsequent chapters describe the actual inspection process in more detail.

The comprehensive evaluation inspection should begin with a thorough review of the project files and information database, including records of site conditions, project design, dam construction and performance, maintenance records, and earlier inspection reports. If the records are incomplete or non-existent, an inspector or dam owner should gather the needed information, or compile a

new database that becomes a permanent part of the owner's project files.

A comprehensive evaluation inspection should begin with a review of the hydrologic/hydraulic calculations and geotechnical data to determine if the structures meet current accepted design criteria and practices. If these calculations have not been performed, inspectors should make an estimate of the adequacy of the spillway and embankment stability based on the best available information, followed by recommendations for a hydrologic and hydraulic analysis of the watershed and the dam, and a geotechnical evaluation of the embankment and foundation. It is important that the calculations include overtopping and spillway capacity estimates, slope stability analyses, and embankment seepage analyses. Obviously, if the same people perform the dam inspections every time, they will not have to review the hydrologic/hydraulic calculations and geotechnical data before every inspection.

A visual inspection or field examination of the dam, its appurtenant works, and the surrounding areas is conducted after the file review, and information database is completed. The visual inspections are made to evaluate the safety and integrity of the dam and appurtenant structures in all aspects. Underwater examinations should be performed as needed. Access routes to the dam site and to the individual operating stations should be examined for general suitability, for reliability during periods of adverse weather, and for access during periods of high water or emergencies. A review of the Emergency Action Plan or Emergency Response Procedures should be performed if one has been prepared.

After considering all relevant file data and completing the field inspection, conclusions should be made regarding needed monitoring, or remedial measures for repairing, strengthening, altering, or restricting operations. Necessary monitoring and corrective actions and their timing should then be recommended. Recommendations should also be made for conducting more site investigations and engineering analyses if they are

needed. Chapters 3 through 8 give added details on how to prepare for, carry out and report the visual inspection.

In some cases, enough information might not be available in the files or from what can be observed on the ground to provide a solid knowledge base, or a basis for knowing that the dam, its appurtenant works, or the foundations are adequate as they currently exist. In other cases, dam plans and design information may not be available or may not have been prepared before the dam was constructed. In such instances, inspectors should recommend specific investigations that might be necessary to obtain the data, including surveys, geologic mapping, drilling and sampling, laboratory testing, installation of instrumentation, hydrologic studies, geotechnical, and other engineering analyses, especially if the dam's integrity is in question. The recommendations for investigations should be included in the inspection report that is completed following the visual inspection.

A detailed inspection report should be prepared after the visual inspection is performed to document the background information, design, construction and operational issues, as well as the field examination, with conclusions and recommendations. The report should also include pertinent photographs, a completed Scheduled Dam Safety Inspection Form (Appendix B), and relevant supporting data. The report should be placed in the owner's project files and submitted to CDSO if required under current CDSO regulations. Chapter 9. describes recommended procedures for documenting and reporting dam safety inspections.

Comprehensive evaluation inspections should be the initial inspection for all dams, regardless of hazard classification. After that, they should be performed on high hazard dams every two years, unless otherwise required by current CDSO regulations. comprehensive evaluation inspections are not normally carried out on a routine basis on low and significant hazard dams unless changing conditions call for them.

Comprehensive evaluation inspections typically are made by a team of one or more professional engineers, geologists, or qualified technicians, accompanied by the dam owner or his representative. The composition of the group is determined by the type of dam and its appurtenant works, and the condition of the dam. The required qualifications of personnel carrying out comprehensive evaluation inspections are described in Chapter 3. Inspectors must be familiar with the design and construction of dams and qualified to make assessments of structure safety.

In summary, a comprehensive evaluation inspection should follow the steps outlined below:

- Step 1.** Existing data are collected, reviewed, and compiled in an information database (as discussed in Chapter 3.). If a dam has instrumentation, the data and analyses of the data should also be collected and reviewed. If an information database is already compiled in a project file, the first step consists of a file review.
- Step 2.** Using the existing data, an inspector assesses the embankment, spillway, and outlet adequacy and performance. The embankment must be stable under all operating conditions, and the spillway and outlet must be capable of safely passing the design flood. The absence or insufficiency of information essential to this part of the inspection (such as foundation characteristics, materials engineering properties, hydrological data, hydraulic analysis, and site seismicity) is noted, and actions required to obtain the information are recommended.
- Step 3.** A visual inspection (or field examination) is then performed to assess the present operational status of the dam, to find existing or developing dangerous conditions, and to determine the risk to the downstream areas. (Field examination techniques are described

in Chapters 4 through 8.) An inspection checklist is an excellent tool to guide an inspector during the field examination. Photographic documentation should cover all components of the dam, including components that are in good condition as well as components that are deteriorating or damaged. Photography of potential downstream hazard areas should also be obtained.

- Step 4.** The need for more information should be noted in the inspection report. If necessary, supplemental data should be acquired by exploratory drilling, laboratory testing, reference to published hydrological data, estimation, and special studies.
- Step 5.** Using the available information, analyses, supporting calculations, and field findings, an inspector prepares a list of conclusions and recommendations.
- Step 6.** The observations made during the field inspection, the analytical findings, conclusions, and recommendations are documented in a comprehensive inspection report that may include appendices for special studies, laboratory and field-testing, revised flood estimates, photographs and other supporting data. The Routine Dam Safety Inspection Form presented in Appendix B, which includes a comprehensive Inspection Checklist, should be completed and included in the report. If the dam safety ratings on the Scheduled Dam Safety Inspection Form change from the earlier ratings, an inspector must provide documentation to support the revised ratings.
- Step 7.** After or during the preparation of the inspection report, inspectors should discuss the results of the inspection with dam owners or their representatives to share the results with them. It is important that dam owners are

acutely aware of the findings and recommendations, particularly if deficiencies were discovered, and repairs or further evaluations are required. Inspectors should encourage dam owners to perform all recommended repairs, evaluations, monitoring, and maintenance within a time that is suitable for the necessary action.

Step 8. The comprehensive evaluation inspection report may need to be submitted to the CDSO for high hazard dams, and for other dams if required by current regulations. This step also includes any report revisions that may be asked for by the CDSO. A copy of the report should be placed in the dam owner's project file.

Step 9. Finally, inspectors should summarize and document the dam's deficiencies in the Dam Health and Rehabilitation Monitoring Application (DHARMA) administered by the CDSO (2016a and 2017).

The CDSO should be contacted for more information concerning DHARMA, which provides a complete information database that should be assembled during the comprehensive evaluation inspection if not already available.

2.3.2 Scheduled Inspections

Scheduled inspections are performed to gather information on the current condition of the dam and its appurtenant works. This information is then used to establish needed repairs and repair schedules, and to assess the safety and operational adequacy of the dam. Scheduled inspections are also performed to evaluate previous repairs.

The purpose of scheduled inspections is to keep the dam and its appurtenant structures in good operating condition and to maintain a safe structure. As such, these inspections will minimize long-term ownership and liability costs and will extend the life the dam. scheduled inspections should be performed more often than comprehensive evaluation inspections to detect at an early stage

any developments that may be detrimental to the dam. These inspections involve assessing operational capability as well as structural stability to detect any problems and correct them before the conditions worsen. The field examinations should be made by the personnel assigned responsibility for monitoring the safety of the dam. If the dam or appurtenant works have instrumentation, the individual responsible for monitoring should analyze measurements as they are received and include an evaluation of that data. The Scheduled Dam Safety Inspection Form should be completed during and after the field visit.

Scheduled inspections should include the following four components at a minimum:

- 1) File review of past inspection reports, monitoring data, photographs, maintenance records, or other pertinent data as may be required;
- 2) Visual inspection of the dam and its appurtenant works;
- 3) Preparation of a report or inspection brief, with relevant documentation and photographs. The report should be filed in the dam owner's project files.
- 4) Education and training if someone other than the owner is performing the inspection.

Scheduled inspections begin with a review of past inspection reports and a cursory review of the complete project file if necessary, paying attention to potential trouble spots. Inspectors should then perform a visual inspection or field examination of all physical features and any adjacent endangering conditions. The field examination is a comprehensive search for evidence of deterioration of materials, developing weaknesses, risky hydraulic and structural behavior, growth of excessive vegetation, presence of rodents, and soil erosion problems. An inspection checklist is a valuable tool that can be used during scheduled inspections. The field examination should include photographic documentation of all the components of the dam, including components that are in good condition as well as components that are deteriorating or damaged.

Scheduled inspections should be performed at regular intervals, usually at least once every year, although in exceptional cases more frequent inspections might be called for. Comprehensive evaluation inspections may be carried out in place of scheduled inspections, and the field examination procedures are the same for both. For example, if the subject dam has a high hazard classification and requires comprehensive evaluation inspections periodically, an additional scheduled inspection is probably not needed during the years that the comprehensive evaluation inspection is conducted. In this example, the scheduled inspections would be performed in the years that the comprehensive evaluation inspections are not made.

For low and significant hazard dams, comprehensive evaluation inspections are not routinely conducted after the first comprehensive evaluation inspection. Therefore, the scheduled inspections are a primary component in the dam operation plan. Adjustments can be made in the examination frequency where unusual or special circumstances warrant. Successive inspections may be made in different months of the year to benefit from extremes in reservoir stages and differences in seasonal climatic effects.

The dam owner or maintenance personnel familiar with the project typically conducts the scheduled inspections. The dam safety professionals involved in the comprehensive evaluation inspections may accompany an inspector if requested. Inspectors are guided by their familiarity with the complete history of the dam. Their observations, evaluations, and recommendations should be documented on the Scheduled Dam Safety Inspection Form or an inspection brief and placed in the owner's project file. Field examination techniques for scheduled inspections are discussed in Chapters 4 through 8, and a sample checklist for field examinations is contained in Appendix B. The field examination procedures for scheduled inspections are the same as those employed during comprehensive evaluation inspections.

2.3.3 Special (Unscheduled) Inspections

Special inspections may need to be performed to resolve specific concerns or conditions at the site on an unscheduled basis. Special inspections are not regularly scheduled activities, but are usually made before or immediately after the dam or appurtenant works have been subjected to unusual events or conditions, such as an unusually high pool level, rainstorm, or a significant earthquake. A special inspection may also be performed during an emergency, such as an impending dam breach, to evaluate specific areas or concerns. They are also made when the ongoing surveillance program identifies a condition or a trend that appears to warrant a special evaluation.

Special inspections should focus on those dam components that are affected by the unusual event and should include at least three elements: 1) review of relevant files or data, 2) visual inspection, and 3) report preparation. An inspection report form may or may not be completed, depending on the specific situation. The findings may be recorded in a log book or on a sheet of paper (inspection brief) that is then placed in the project files. More detailed site investigations may be required (such as drilling, surveys, or seepage flow estimates) if the special inspection reveals deteriorating dam conditions. Photographic documentation is usually included as part of the inspection if damage to dam components has occurred.

2.3.4 Informal Inspections

The last type of inspection, an informal inspection, is a continuing effort by on-site personnel (dam owners/operators and maintenance personnel) performed during their regular duties. Informal inspections give a continuous surveillance of the dam and are critical to the proper operation and maintenance of the dam. They consist of frequent observations of the general appearance and functioning of the dam and appurtenant structures.

Normally, people who are not professional engineers or geologists will make informal inspections. They could be the dam owners, operators, maintenance crews, or other staff whose duties place them near the dam at regular intervals. These people are the “first line of defense” in assuring safe dam conditions, and it is their responsibility to be familiar with all aspects of the dam. Their vigilance in walking the dam, checking the operating equipment, and noting changes in conditions may prevent serious mishaps or even dam failures.

Informal inspections are critical and should be performed at every available opportunity. These inspections may only cover one or two dam components as the occasion presents itself, or they may cover the entire dam and its appurtenant structures. The informal inspections are not as all-encom-

passing as comprehensive evaluation, scheduled, and special inspections and will only require that a formal report is submitted to the dam owner’s project files if a condition is detected that might endanger the dam.

2.4 Emergency Actions

During a safety inspection (usually and informal inspection) a condition may be discovered that requires the dam owner to take immediate measures to prevent the problem from worsening, including contacting repair contractors, notifying local emergency authorities, and notifying downstream residents or occupants. Depending on the severity of the condition, an emergency alert may need to be issued. See *Guidelines for Developing Emergency Action Plans for Dams* (CDSO 2016b) for the emergency condition level (**Blue**, **Orange**, or **Red**) that corresponds to various signs of distress at a dam.

Chapter 3. PREPARING FOR AN INSPECTION

A thorough and effective dam inspection requires a lot of preparation including (1) assembling a knowledgeable inspection team, (2) reviewing project records, (3) collecting the equipment that will be needed, and (4) scheduling interviews, file reviews, and onsite visits. The safety of dam inspectors should always be kept in mind when preparing for and carrying out a dam inspection.

3.1 Assembling the Inspection Team

The knowledge needed by an inspector or inspection team depends on the type of examination being performed, the type of dam, and the site conditions. The inspection team members should be familiar with dam design, the causes of dam failures, and the telltale signs that reveal problems or potential concerns. Following a visual inspection, the team members should compare their individual assessments of observed conditions and prepare a single composite report.

Dam inspectors are responsible for the safety of life and property, so they need to recognize when their level of knowledge is inadequate. The Central Dam Safety Organization and the State Dam Safety Organizations provide specific inspection training for engineers, technicians, maintenance personnel, and administrators responsible for dams.

3.1.1 Comprehensive Evaluation Team

A comprehensive evaluation includes a visual inspection of a dam and its appurtenances. The lead inspector of the team is required to be a qualified engineer who has broad experience in dam design and operation. The needed size of the team and the competencies of its members depend on the type of dam and the condition of the dam or the kinds of problems that may be present. Because a comprehensive evaluation involves study, investigation, and analyses of

many diverse subjects and conditions, together with assessments of their interrelationships, skilled specialists with the broadest experience in all phases of dam design and construction engineering are required. Inspection team members may include civil engineers, geotechnical engineers, hydrologists, geologists, structural engineers, and other specialists, depending on the characteristics of the of the dam.

The lead inspector may perform the visual inspection alone if he has broad-based educational and technical experience with dams and if the dam does not have complex features or severe problems. On larger, complex dams it is likely that no single person will have all the expertise that is required, and a team inspection will be needed. Larger organizations may be fortunate enough to have staff that includes mechanical engineers, hydrologists, electrical engineers, geotechnical engineers, and other specialists available to evaluate specific features of a dam. Inspection team members, regardless of their field of expertise, need to have knowledge of dam design methods, construction techniques, and operational requirements. The dam owner or his representative should always be present during a comprehensive evaluation inspection to learn as much as possible about the dam and potential problems.

3.1.2 Scheduled Inspection Team

A scheduled inspection (usually a pre- or post-monsoon inspection) is typically performed by the person(s) assigned responsibility for the operation or maintenance of the dam and its appurtenant works. The person assigned this responsibility should be familiar with the dam and should possess sufficient knowledge to make an accurate assessment of the dam's condition.

3.1.3 Special (Unscheduled) Inspection Team

The dam owner, dam operator, or dam tender typically performs informal inspections and special inspections. Again, an engineer or another qualified dam safety professional may be required to assist in a special inspection depending on the specific situation.

The dam inspector(s) should be thorough and organized. To readily identify trends, it is necessary to maintain records of performance in an orderly way. Where instrumentation and seepage measurements are available, inspectors should evaluate these files at regular intervals and in a format that makes them easily interpreted. Likewise, observations made during field examinations should be recorded and maintained in the project file in such a way that trends can be visualized readily. Specific recommendations for recording and maintaining data and information appear in other chapters of this manual. If inspectors are unable to interpret or evaluate observed conditions, they should seek the advice of more qualified dam safety specialists.

3.1.4 General Inspection Team Requirements

There may be times when specialists must apply scientific and engineering knowledge and experience to a wide range of tasks during a dam inspection. These tasks may include interpretation of the geologic structure of dam sites, appraising the engineering properties of the foundation and embankment, predicting and analyzing seepage, calculating and analyzing stresses and stability of embankments and appurtenant structures, evaluating the runoff from watersheds, estimating the capacity and flow in spillways and outfalls, evaluating the mechanical and electrical equipment if present, and analyzing instrumentation and other monitoring data. The proper performance of these tasks usually requires qualified individuals with specific expertise. Occasionally there may be a need for the services of a mechanical engineer, an electrical engineer, or a seismologist. The assistance of

engineering and geological technicians, surveyors, and laboratory technicians may also be required. A final coordinated evaluation is then made by a senior inspection team member who is broadly experienced in all aspects of dam engineering, especially design. This person is usually a civil engineer, but can also be a geotechnical engineer if the dam is an embankment type.

Highly specialized services may also be required for some dams. These services may include underwater visual inspections, televised examinations of conduits, or geophysical investigations. These services are readily available through specialized firms and will usually require advance notification and contractual arrangements. Underwater divers will need to have enough details of the project to plan safety and procedural particulars of the visual inspection. Televised conduit inspection may be necessary when conduit diameters are small or when direct access is not workable. Explorative drilling or other geophysical services may be required if any additional subsurface information is needed.

The field examination will normally consist of interviews with the owner or operating personnel, a visual inspection of the dam and all appurtenant structures, and observation of the watershed and downstream areas. The manner in which the visual inspection proceeds will depend on the site and type of inspection being made. The performance of the visual inspection will be influenced by weather, ground cover, the condition of the structure, personal safety considerations, purpose of the inspection, operational considerations, and even the inspection team's level of experience. The visual inspection team should anticipate these conditions to ensure that proper equipment, clothing, and safety items are on hand. An inspector should consider situations when additional personnel will be required to conduct the visual inspection properly and to assure safety. Planning ahead for such contingencies may eliminate the need for a return trip.

3.2 Review of Project Records

Proper preparation is essential for safety inspections of all types. The project files should be examined as the initial step in every dam safety inspection. The extent of the review depends on the kind of inspection and how familiar an inspector is with the dam. A complete dam project file should contain four general kinds of information that constitute the dam information database: 1) background information, 2) design information, 3) construction records and 4) operation performance records. This information should be reviewed by and be familiar to the inspecting personnel. Making a checklist of items to be considered before the inspection is helpful and will ensure that relevant documents are not overlooked.

A dam project file is essentially a compilation of all information pertinent to a specific dam. A thorough assessment of dam safety cannot be made without ready access to this information. Each organization may have its own guidelines concerning the structure of the dam project safety file; however, it should contain the four general types of information listed above. The goal of the dam project file is to provide ready access to information that can be used to help prepare for conducting a dam safety inspection, evaluate the observations made during a field examination, and have pertinent information available in case of an emergency.

3.2.1 Recommended Information Database for Project Files

The project files created over the years are essential for a periodic inspection program. These records provide data that form a basis for making engineering evaluations and decisions and help familiarize and orient an inspector. The project files may also be needed for reference during emergency situations. Knowledgeable personnel familiar with a dam may be unavailable during a crisis, so the information in the archives may be required to help resolve problems.

This source of ready reference is also needed because of personnel turnover and

organizational responsibility. Seldom will an individual have been continuously involved in a project since its inception, and staff assignments change. Collecting this assorted project record and maintaining it as a continuing record in a permanent file is, therefore, essential to an effective periodic inspection program and ongoing dam maintenance. When necessary, special exploration and testing, analytical studies, and reevaluation with advanced technology may be performed to obtain necessary information for the project files and inspection efforts.

Project files should be compiled in a systematic format. A standardized, orderly, pre-determined arrangement will facilitate the use of the records and accommodate future additions more readily. Generally, the project files will grow with time as new and additional information is added.

The extent of the file review will vary with the type of inspection being performed. For example, if a comprehensive evaluation inspection will be conducted by a new inspector, the entire project file should be thoroughly reviewed. If an informal inspection is performed by the dam maintenance staff, only the previous inspection reports may need to be examined. In any case, the project files should contain a complete information database for the dam in question.

3.2.2 Types of File Review

Generally, three types of file review may be performed as part of a dam safety inspection: (1) preliminary file review, (2) comprehensive file review, and (3) informal file review. The type of review will depend on the kind of inspection and an inspector's familiarity with the dam.

Preliminary File Review

A preliminary file review is an initial review of general information about the dam that will be inspected. Sufficient information is examined to:

- Select the appropriate records to review in detail based on features of the dam to be inspected.

- Schedule the visual inspection (time of year for the desired operating condition, and the amount of time the inspection will take).
- Select members of the inspection team.
- Arrange for the operation and visual inspection of certain features.

Conducting a preliminary file review involves gathering and examining general information about the dam to be inspected. The preliminary examination gives an inspector an overall picture of the dam and helps to discover inspection items that need further research and preparation.

The aims of the preliminary data review are to:

- determine the owner of the dam,
- note the exact location of the dam,
- ascertain the type of inspection to be performed,
- identify the features to be inspected and features with noted deficiencies,
- identify upstream and downstream conditions,
- verify the timeframe for the visual inspection (time of year and amount of time the inspection will take), and
- determine the extent of comprehensive review.

Comprehensive File Review

A comprehensive file review covering all features of the dam should be done after conducting a preliminary review of the file data. The amount of information reviewed and evaluated before the field examination will depend on the type of the inspection and the potential problems that may be present. The entire project file should be considered for comprehensive evaluation inspections. If the same people perform every inspection, they may be able to spend less time on some parts of the file and more time on other parts. If an inspection is the first comprehensive evaluation inspection for inspectors, they should review the entire file.

Preparation for a scheduled inspection may include an examination of relevant portions of the archive only, such as operational performance records, construction records of the major dam components, and design criteria related to dam spillways and outfalls. If the dam has known problems that are being monitored, that portion of the files that deals with the problem area(s) should be reviewed. Each file review should be tailored to the specific type of inspection and the potential problems that may be encountered.

The goals of a comprehensive file review are to:

- reveal potential dam safety deficiencies that may not be visible during the field examination, and note potential dam failure modes,
- help interpret conditions that may be seen onsite, and
- help develop an inspection plan that will ensure a thorough onsite dam safety inspection.

Conducting a comprehensive review of available data involves gathering and reviewing all pertinent information about the dam to be inspected. The following general criteria should be considered during the detailed data review:

- The type of dam to be inspected and its individual features.
- The intended use of the dam and reservoir.
- The underlying and surrounding geologic conditions.
- Design and construction details pertinent to the safety of the dam.
- Operational issues that affect performance.
- The presence of instrumentation, and results of data analysis.
- Conditions that might, at some point, affect the structural integrity of the dam (e.g., fault zones, lack of drainage features, alkali-aggregate reactive concrete, and increasing seepage).

- Past problems with the performance or operation of the dam or any of its features that need to be considered during the inspection.
- Recent difficulties with the foundation or abutments (during construction or operation) that need to be considered during the inspection.

If a comprehensive evaluation dam safety inspection is being performed, design and construction details should be compared to current criteria to determine whether materials or procedures used for the building of the dam present a threat to the safety of the dam by current standards.

Informal File Review

An informal file review consists of reviewing select parts of the dam project file in preparation for informal and special inspections. For example, an inspector may only consider the earlier inspection reports or report forms prior to performing an informal inspection. In some cases, an inspector may review only the project photographs. In most cases, informal reviews are done by people thoroughly familiar with the dam who are concerned about a specific dam feature.

3.2.3 Background Information

Background information includes general information and data that define the dam and its environment. This information is used to become familiar with the type of dam, its location, and outstanding features or concerns. The following list summarizes the background information that should be included in the project files.

- Dam owner and responsible parties
- Dam location
- Site topographic mapping
- Surface and subsurface geology
- Site geology reports
- Exploration techniques employed
- Regional and site seismicity
- Regional seismic and earthquake history
- Underground mine maps

- Soil surveys and land use
- Aerial and site photographs
- Correspondence
- Emergency Action Plan
- Expert consultant reviews
- History of site before construction

Over time, a situation or condition may be created upstream or downstream of a dam that has unfavorable impacts on safety. Examples of upstream conditions that could affect the dam include the construction of another dam or a water conveyance system or the creation of new population centers along the perimeter of the impoundment. A downstream condition might be development in the floodplain that would change the dam's hazard classification. Inspectors should try to discover any new situations or changes in existing conditions prior to conducting the field examination.

As part of the background research, inspectors should research available seismic history and mapping for the region where the dam is found. Seismic zones that are distant from the dam may have an impact on the structure if an earthquake occurs.

3.2.4 Design Information

Design information for dams varies widely in form and detail. Records may be simple pencil sketches with brief notations on the dimensions, or detailed plans and specifications along with complete design and geotechnical reports. The availability of the design documents for review will depend on the completeness of the records kept by the dam owner, design agency, engineering firm, and administrative office.

The dam project file should also be carefully reviewed for any documented modifications to the original design. The inspecting personnel must be able to verify structural elevations and dimensions, locations and sizes of appurtenances, and variances from the original layout. Design changes, including items that may have been dropped during construction, must also be identified. As-

built drawings should be reviewed when available.

For some dams, no design or technical information will be available. In the case of an initial formal technical inspection, the review of a design may not be possible until the owner has been contacted or interviewed. The location or even the existence of design documents may not be known until this first discovery is made.

Familiarity with the geotechnical aspects of the design can be gained through a review of available boring logs, soil laboratory test results, seismic studies, and geophysical data. The extent to which this review is necessary will depend on the location, size, purpose, history of problems, and age of the dam. Because foundation and abutment areas cannot be visually inspected, knowledge of the geology of these regions and how any geologic problems were considered during construction are essential. Evaluation of existing geotechnical and geologic aspects of a design may be performed best by an experienced geotechnical engineer or engineering geologist. The need for expert evaluation depends upon the purpose of the inspection, the size of the dam and its performance history.

Hydrologic information is used to design the capacities of the spillway and outlet works, and to calculate how much freeboard is needed. Rainfall and runoff are important considerations when calculating the needed spillway discharge capacity. Over time, there may be changes to the land upstream that will affect hydrologic conditions, such as land clearing, residential and industrial development, and conversion of forest to agricultural land. These changes could affect the amount and timing of runoff, the resulting reservoir level, and the amount and rate of spillway discharge. Therefore, during a formal technical inspection, an inspector must look at how the hydrologic design was developed and whether any conditions have changed which could affect the dam design. If the hydrologic information is dated, a hydrologist may have to reevaluate the data and method used to determine if changes need to be made to the

dam or the spillway based upon current conditions or design standards.

Inspectors should also examine downstream conditions to assess whether any changes have occurred that could affect the dam hazard classification or discharge characteristics. Construction of new buildings, houses, or other structures within the potential area of flooding could change a dam's classification from low or significant hazard to high hazard. This can affect the type and frequency of inspections that are required, as well as CDSO reporting requirements, depending on current regulations.

3.2.5 Construction Records

Construction records depict the quantities and types of materials used, variances from design plans and specifications, and any unusual geologic or other conditions encountered. Quality control efforts that were employed during construction may also be available, along with field and laboratory testing results for the dam materials. Remedial actions to correct significant problems which developed during construction, such as removal of unsuitable foundation soils, may have required the preparation of supplemental plans, specifications, and other project documents. Alterations to plans and specifications may be recorded in many different forms including inspector's reports, letters, diaries, meeting minutes, special investigation reports, photographs, plan revisions and specification alternates. Unfortunately, such alterations may or may not appear on as-built drawings. The complete omission of a design item during construction is also not unusual.

Sampling and testing records of the soil used in embankment construction are critical to understanding the stability and seepage potential of embankment dams. This information is often collected during construction and enclosed in the building documentation report. Embankment soil density and moisture sampling and testing are two of the most commonly obtained construction parameters. Control of these two properties and

compaction lift thickness is critical to embankment construction. Soil particle size determinations and soil classification are two more parameters monitored during construction. Complete project files should include information on these important soil properties.

Progress and inspector's reports will record the seasons through which construction was performed as well as document weather, construction equipment, material sampling and testing, and site conditions. When performing the inspection, this information can help evaluate a newly observed or previously known condition at a dam. For example, temperature extremes and dry or wet conditions, which occurred during construction, may have a direct correlation to dam seepage or settlement problems. Project engineers, technicians, the dam owner, and the contractor may need to be interviewed to obtain information about the construction to understand an observed condition fully. Photographs from previous inspections, which would be available in the dam owner's project files, might help to troubleshoot seepage problems along the discharge pipe.

The geotechnical aspects of a design may change during construction because of the unforeseen foundation and abutment conditions such as the presence of a weak or fractured rock zone, or an underlying porous soil layer. Unexpected effects of excavations, blasting, and other alterations on the ground water and hillside slope stability may have been documented in the construction records along with the corrective or mitigative actions taken. When available, photographs provide excellent documentation of construction problems and their resolution.

Construction documents will usually indicate the type of equipment used. For example, these records can help determine the degree of compaction and the rate of construction. The number of passes a soil compactor made for each lift can be used to indicate the level of compaction. The presence or absence of special equipment such as water trucks, discs, or scarifiers could provide clues

to the in-place condition of constructed materials. The type of soil compactor used should be described, including the kind of machine, size or weight class, and the length of the compactor pad feet. It is equally important to determine the types of equipment used in concrete construction such as transit-mix concrete trucks, on-site batch plants, cranes, conveyors, and pumps. It is important to know the type of equipment used to install discharge conduits.

Foundation and abutment preparation is a critical construction task that should be well documented with written records, maps, and photographs. All vegetative and other organic material should have been removed and replaced with suitable, recompacted soil. Records of key trench excavation, abutment preparation, backfilling, and compaction effort can be helpful with troubleshooting foundation drainage issues.

The preparation of the spillway subgrade, especially spillway conduits, should be documented during construction. The type of bedding used, the compaction efforts and the method of backfilling conduit trenches can have a significant impact on the prevention of seepage. Methods of conduit placement and joint sealing are also prominent issues that can help understand problems that may develop.

Specific techniques or methods of construction that were used may have been documented. Hydraulic fills and mine tailings or coal refuse embankments are examples of dams constructed using special methods. Hydraulic fill dams may be more susceptible to seismic forces. Construction of dams with hydraulic fills, mine tailings, and coal refuse are not recommended and should be avoided. These types of structures can be impaired with both stability and environmental issues.

A critical time in the history of any dam is the first filling of the reservoir. Although construction may be over by this time, the reservoir filling might have been documented in construction records. Observations of seepage, cracks and other conditions that

appeared after the dam began impounding water might be found in these files.

Alterations or modifications may occur to a dam at any time after construction is completed. In some cases, an older structure such as a wood crib dam may have been reconstructed by adding earthfill or concrete, completely covering the original dam. Additional soil fill may have been placed on embankment dams to reduce the slopes or to repair defects such as settlement or erosion. Spillways may have been replaced or upgraded if the original structures were deteriorating or damaged. The design and construction records of these subsequent changes, and whether they followed applicable agency requirements, should be reviewed, if available.

Dam owners should beware of modifying their structures without proper design and without obtaining required permits. Such modifications can subject the owner to potential legal and liability issues and could result in regulatory fines, damage payments to downstream property owners, or prison when lives are lost if the dam fails because of the modifications. Inspectors should note any unapproved changes in the inspection report.

3.2.6 Operational Performance Records

Instrumentation data will be the least available information for most dams. Many smaller dams will not have any instrumentation. The purpose and types of instrumentation that does exist should be familiar to the inspection team. Systems for monitoring the performance of a dam can be complex or simple. The more complex systems require experienced personnel to retrieve and evaluate readings and measurements. Even if they do not possess this expertise, inspecting personnel should still be aware of the location, design, and purpose of any monitoring devices to evaluate their physical condition.

All available operation, maintenance, and inspection records maintained by an owner,

regulatory agency, or another entity should be reviewed. Operation records should include any previous monitoring data. Records may be examined before, during, or after the inspection, depending on availability and the field inspection findings.

Data collected from instrumentation and monitoring systems should be stored in the files and kept indefinitely unless qualified technical personnel indicates otherwise. Available monitoring records should be checked for location, the type of instrumentation, the method of data collection, the purpose of instrumentation, and type of data collected. Records may apply to instrumentation added to a dam before it was constructed or afterwards. Instrumentation is usually installed after construction to monitor a specific problem which was not apparent during the original design, or which developed after the reservoir filling is complete.

3.2.7 Sources of Information

The information sources for a specific dam may be in several locations, depending upon the developmental history of the project, previous file maintenance techniques, personnel involved with the dam, and any ownership changes. Engineering firms that have been involved with the dam should have project files concerning the work they performed.

Recent aerial photographs are useful for viewing upstream and downstream conditions and are recommended for use during the dam safety inspections to map or sketch dam features and deficiencies.

In some cases, information might be obtained from the files of the contractor who built the dam, but it will be of limited extent and value. However, the opportunity to get photographs should not be overlooked.

Newspaper accounts will sometimes give helpful information, especially during periods of dramatic events such as huge floods or massive earthquakes. While reliable facts and engineering considerations will seldom be obtained from such accounts, useful photographs may have been taken, or historical events may have been recorded.

If the dam is noteworthy or unusual, engineering and construction contracting periodicals may have published some reliable data concerning its design and construction. Reliable accounts of dams constructed many years ago sometimes appear in old engineering periodicals. Journals and technical publications of engineering associations such as the American Society of Civil Engineers and the United States Committee on Large Dams often have reliable data on dams. However, such data are usually available only for large, notable dams.

Interviews with people associated with the project during its construction and its following operation can sometimes provide answers to specific questions. These people may include contractors' representatives, individual workers, owners, owners' engineers, operation and maintenance personnel, CDSO representatives, and members of the public. Responses obtained by such interviews must be carefully screened and evaluated, considering the involvement and background of each person.

The records and files for existing dams vary in their completeness, quality, and usefulness. Their existence and character would vary with the age of the facilities, the type of ownership, and the project engineer if there was one. In many cases, records (especially of design and construction) may be entirely nonexistent, fragmentary, or inaccurate. It is important, however, that a diligent search is made for all records, because the information there may be vital and unavailable from any other source (e.g., treatment of unusual or difficult foundations). Available data relating to the general area around the dam and reservoir should also be reviewed.

3.3 Inspection Field Kit

A wide range of equipment may be needed by the team to perform the safety inspection well. The equipment needs depend on many parameters such as weather conditions, type of dam, the complexity of design, the state of the dam, instrumentation, and purpose of the inspection. Personal equipment items include clipboards, field notebooks, pencils, pocket

rulers, proper clothing, and pocket knives. Also, a reduced copy of the drawings for the dam being inspected is a convenient means to have design data readily available during the inspection. A listing of general equipment, specialized equipment, and safety equipment and protective clothing which may be useful to the inspection team is given in Appendix A. Contents of a typical inspection field kit are shown in Figure 3-1.



Figure 3-1. Contents of a typical inspection field kit.

Equipment should be maintained properly and stored securely when not in use. Instruments should be adjusted properly, inspected often, and calibrated regularly. Misplaced or damaged equipment can reduce the effectiveness of or even alter the outcome of an inspection.

3.4 Inspection Scheduling

Inspection scheduling depends on many factors, such as who will be present, where the dam is located, the type of inspection, the time of year, and the condition of the dam. All individuals who are to attend the inspection must be notified of the date, time, and location. The scheduled time and date will need to accommodate everyone's personal schedule. Coordination with state and federal agencies, local government officials, industrial owner representatives, engineering consultants, and individual private owners may be necessary. Representatives of divisions or sections internal or companion to the regula-

tory dam safety agency may need to be included. If an interview with the owner, operator, or another individual is to be conducted separately, the meeting location and time should be arranged appropriately. In setting the time for the inspection, time zone changes, and travel times for all parties should be considered. The amount of vegetation on the embankment and the level of water in the reservoir or spillway can also have a direct impact on inspection scheduling.

The dam owner or operating personnel should be notified in advance if they will be asked to assist in the inspection. For example, areas may need to be dewatered, or equipment may need to be operated. Drawdown equipment should be checked at least once per year to make sure it is working properly. Also, arrangements for gate or door keys, transportation, and special equipment should be made ahead of the inspection.

There are two principal criteria for determining the general time frame for a dam safety inspection: the time of year (or season) in which the inspection will take place, and the time it will take to perform the actual inspection. After the general schedule is established, the specific day and time of day can be programmed.

If many or all the features of the dam will be inspected, the date of year or season in which the inspection will take place can be critical. The inspection may need to be performed when the reservoir is at its lowest point or after a large release of water so that those features or areas of the dam that are usually submerged are exposed.

Also, removal from service and inspection of some features may be possible during periods of limited operational requirements. If the inspection requires that certain features be tested or inspected as close to full design load as possible (i.e., maximum reservoir elevation), the inspection may need to occur when the dam is at its normal yearly maximum elevation. This may also allow an inspector to observe equipment as it operates under maximum design loading conditions.

Inspector safety and convenience may play a major role when scheduling a visual inspection. While a dam should be accessible any time of the year for inspections if the embankment area is heavily vegetated, it may be best to inspect the dam when the vegetation is dormant (late fall, winter, or early spring). This may make it easier to find areas where settlement has occurred, embankment cracking has become a problem, and animals have created burrows. Overgrown vegetation is inappropriate for any dam and should not be present to hinder inspection. If snakes are present at the site, the inspection may be scheduled for those periods when the snakes are inactive (cool weather months). Insect presence (bees, ticks) may also be a determining factor for scheduling an inspection. Inspecting a dam when it is raining, snowing, or extremely cold or hot could pose specific health and safety concerns for some inspectors.

The amount of time needed to complete an inspection should also be considered. A comprehensive visual inspection could take a full day or more than one day, and additional travel arrangements may be necessary. In some cases, it may be desirable to return to view an identified problem area under different weather conditions or other circumstances. Return visits and inspections extending more than one day may not require the presence of all parties, who should be so advised. After the features of the dam that will be inspected have been selected, review of the records of past inspections may reveal how long the inspection will take. Experience will also aid in judging an inspection duration.

In summary, the amount of time needed for a dam safety visual inspection depends on the following factors:

- The size and complexity of upstream and downstream areas to be visited.
- The type of inspection being conducted (e.g., a comprehensive evaluation inspection will take longer than a special inspection).
- The number and complexity of appurtenances to be inspected.

- Whether the inspection requires operation of drawdown or spillway structures.
- The size of the structure. If the dam is a long embankment dam, it will take considerable time to walk and inspect all the features (to inspect the upstream slope, downstream slope, and crest). If it is a large concrete dam, it may have several galleries.
- The size of the inspection team.
- The condition of the dam and its appurtenant works. Dams in bad condition may require significantly more time to observe and document the conditions.
- Dams inspected during inclement weather will need more time.
- Underwater inspections and conduit televised video recordings will take considerable time.
- Whether the reservoir will be inspected in addition to the dam, and what method of inspection will be used.
- The location of the dam; dams that are a considerable distance from an inspector's office will need significant travel time.
- Unknown, unexpected conditions.

3.5 Inspector Safety

Inspectors should be aware of and plan for potentially hazardous site conditions that may be found at dams. They should use proper safety gear and clothing when needed, and should always use extreme caution when performing visual inspections of dam spillways, embankments, riprap areas, and shorelines. Potentially dangerous areas and hazards include steep or wet embankment slopes,

spillways with high sidewalls or flowing water, spillway conduits, confined spaces, riprap areas with large stones, outlet structures holding water, shorelines with riprap and deep water, concrete embankments, sinkholes, outlet banks, and high grass or bushes. Some of the dangers presented by these features include slipping, falling, drowning, tripping, lack of oxygen, or presence of noxious gasses, stepping in holes, snakes, and bee stings.

Low head dams constructed across streams and rivers also present a safety hazard in the area just downstream of the dam. The whirlpools, hydraulic jumps, and eddies created from the discharging water are extremely dangerous to boaters and swimmers, and there have been many drowning accidents that have occurred in such areas. It can be difficult or impossible for swimmers and boats to escape from this area, especially during periods of increased flow following precipitation events. For this reason, these dams are often referred to as “drowning machines.”

Some dams are in remote areas where people living in the region are involved in illegal activities such as drug labs or drug cultivation. In cases such as this, intruders, such as dam inspectors, may not be welcome and could be in danger of physical harm by the people taking part in the illegal goings on. If a site has known safety hazards, it is essential that the visual inspection is carried out by more than one individual. The use of two inspectors is always a splendid idea because of the potential to slip and fall into the water or down the embankment.

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Chapter 4. INSPECTING EMBANKMENT DAMS

The purpose of this chapter is to help owners and inspectors identify conditions that threaten the safety and long life of the dam. Although some of these conditions can be corrected by normal maintenance, more severe deficiencies may require further investigation by qualified professionals with expertise in specific areas of concern. The end of this chapter contains sketches that can be used to help the owner or inspector identify and classify problems found on the embankments of dams.

As described in Chapter 2, there are four types of dam safety inspections that typically will be performed: 1) comprehensive evaluation inspections, 2) scheduled inspections, 3) special (unscheduled) inspections, and 4) informal inspections. This chapter covers all four types of inspections on embankment dams but focuses on the embankment structure only. Additional embankment dam features, such as spillways, outlets, and general areas are covered in Chapter 6.

4.1 Types of Embankment Dams

Embankment dams include any dam constructed of natural soil materials. This includes the following general types of dams:

- Earth Dam (or earthfill dam) – An embankment dam in which more than 50% of the total volume is formed of compacted inorganic soil material obtained from a borrow area.
- Homogeneous Earthfill Dam – An embankment dam constructed of similar earth material throughout, except for the inclusion of internal drains or drainage blankets; distinguished from a zoned earthfill dam.
- Rockfill Dam – An embankment dam in which more than 50% of the total volume is composed of compacted or dumped permeable natural or crushed rock.
- Zoned Embankment Dam – An embankment dam, which is composed of zones of selected materials having different degrees of porosity, permeability, and density.

The visual inspection procedures and information presented in this chapter can be applied to all the several types of embankment dams. The information is presented for each feature of the embankment, including the crest, upstream slope, downstream slope, abutments, and groins.

The conditions or problems that may be found on embankments can vary depending on the location. For example, seepage typically occurs on the downstream slope areas and in the abutments and groins, while beaching and damage from wave action occur on the upstream slope. Some types of problems can develop anywhere on the embankment, such as inappropriate vegetative growth, cracking, or erosion. Tailwater on the downstream slope of an embankment can saturate the soils and lead to embankment instability; the potential for backwater should be considered.

Typically, the cause of the problem and safety concerns should be determined before any repairs are made on dams. However, if the problem is severe or an emergency is developing, emergency response actions may be required immediately. Short-term repairs, downstream notification, and other measures may be necessary for such instances. Short term measures may include water level lowering, embankment stabilization, spillway enlargement, or controlled breaching if the situation becomes critical.

Inspecting dams to identify and resolve the concerns addressed in this chapter can minimize or eliminate the chance of dam deterioration or failure. Inspectors should be on the lookout always for any conditions that could contribute to dam failure.

4.2 Inspection Procedure

Typical features that require inspection and are common on embankment dams are shown in Figure 4-1. Dam features and descriptions are referenced looking in the downstream direction. For example, for an inspector standing on the embankment crest and looking downstream, the right abutment is to his right, and the left abutment is to his left. Other features common at embankment dams that are not shown in Figure 4-1 include rock toe drains with piping, cutoff trenches, and riprap groin areas.

4.2.1 Planning a Route

It is helpful to prepare an inspection route in advance to assure that every part of the dam will be visited. An inspector can take many different approaches to examining a dam, but the selected method should be systematic to ensure that all features are covered and to make the best use of the time available. A recommended sequence to assist with a visual inspection starts at the top of the dam and proceeds downward. Sometimes it may be more efficient to inspect the easiest, or most readily accessible areas first, or those areas of known problems. However, no matter where an inspector is located on the dam or spillway, he should stop periodically and look

around for 360 degrees to observe other features from that vantage point.

- 1) Dam crest – Walk across the dam crest from abutment to abutment, observing both upstream and downstream slopes while inspecting the crest surface.
- 2) Upstream and downstream slopes – Walk across the slopes in a parallel or zig-zag pattern along the embankment from abutment to abutment, starting with the upstream slope. Special attention should be paid to the downstream slope below the elevation of the reservoir.
- 3) Embankment-abutment contacts – Walk the entire length of the embankment-abutment contacts (groin) on both sides of the dam, on both the upstream and downstream embankments (do in conjunction with slope inspections).
- 4) Principal spillway – Observe all accessible features of the principal spillway and its outlet. Inspect the inlet while performing the upstream slope inspection. Inspect the outlet during or after the downstream slope inspection is completed.
- 5) Auxiliary spillway – Walk along the entire length of the auxiliary spillway in a back and forth manner.

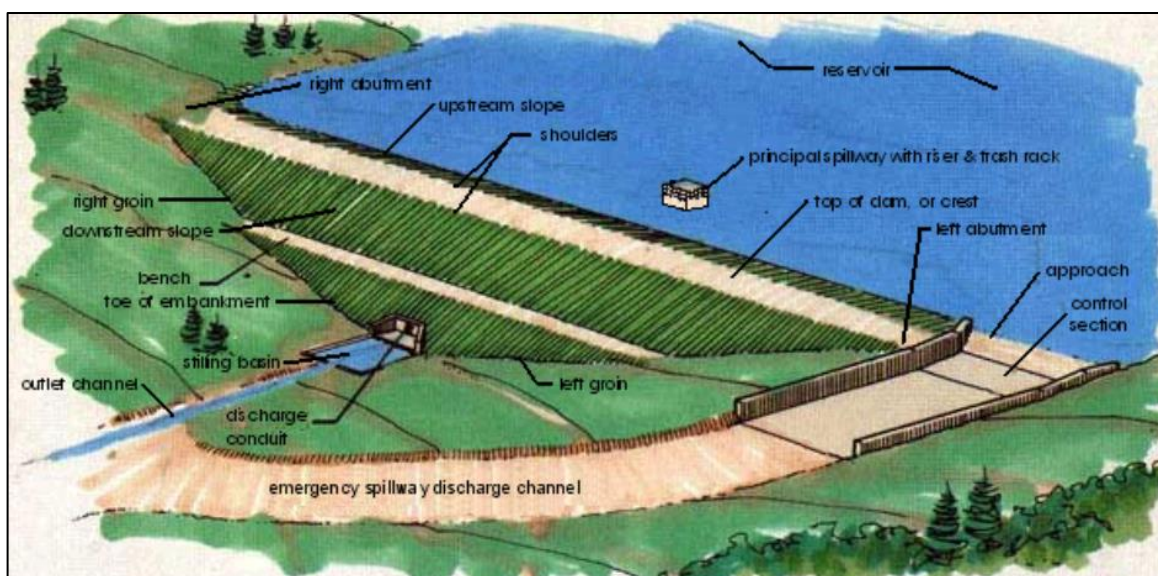


Figure 4-1. Illustration of typical embankment dam features (the left and right sides of the embankment are referenced by looking in the downstream direction).

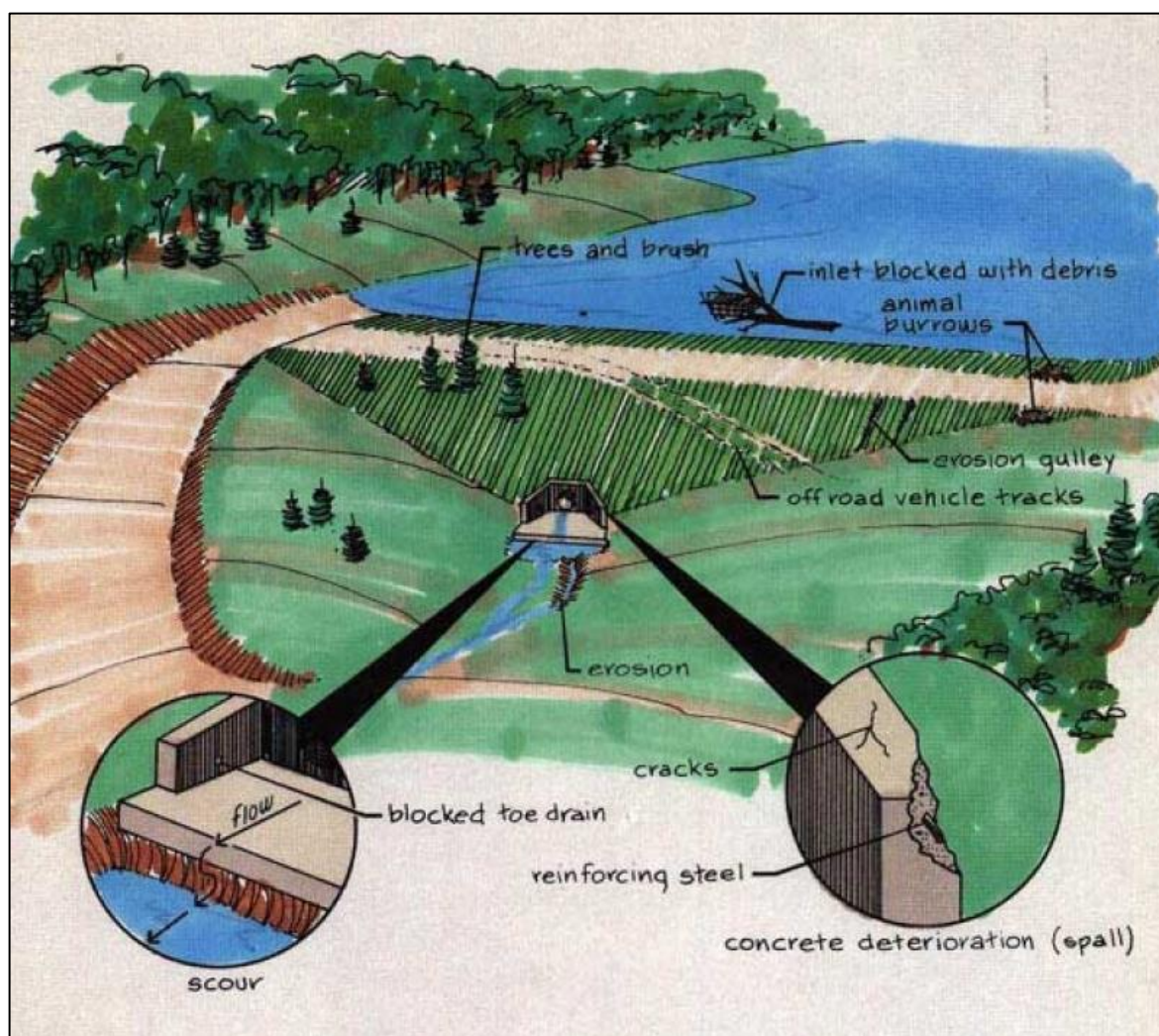


Figure 4-2. Illustration of typical embankment dam features requiring visual inspection.

- 6) Abutments – Traverse abutments in a practical manner to gain a general feel for the conditions, which exist along the valley sidewalls.
- 7) Outlet works and downstream channel – Carefully inspect outlet works and reservoir drains that may be present. Travel the route of the stream below the dam to find residences and property that can be affected by dam failure.
- 8) General areas – Drive or walk along the perimeter of the reservoir and other upstream areas. Carefully inspect all other appurtenant works that may be present at the dam.

Some typical embankment dam features requiring visual inspection are illustrated in Fig-

ure 4-2. Additional details of inspection procedures for selected features are given in following sections.

4.2.2 Embankment Slopes

The general technique for inspecting the slopes of an embankment dam is to walk over the slopes as many times as is necessary to see the entire surface area. From a given point on an embankment slope, an inspector can usually see minute details for three to six meters in each direction, depending on the roughness of the surface, vegetation, or other surface conditions. Therefore, to ensure that the entire face of the dam has been covered, an inspector must repeatedly walk back and forth across the slope until the whole area has been viewed, giving greater scrutiny to the downstream slope below the pool elevation.

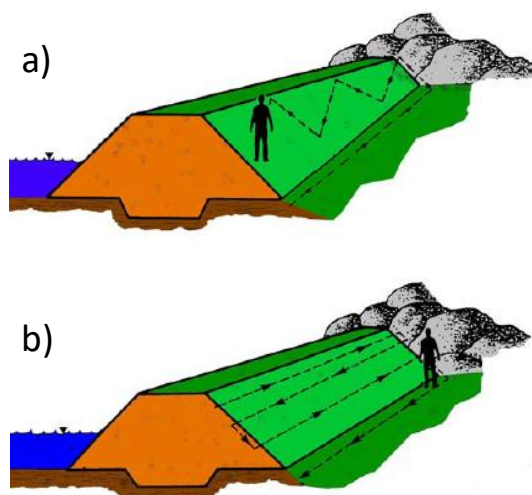


Figure 4-3. a) Zigzag, and b) parallel inspection path on an embankment slope.

The following two patterns can be used for walking across the slope:

- 1) **Zigzag** – A zigzag path (Figure 4-3a) is one recommended approach for ensuring that an inspector has completely covered the slopes and crest. It is preferable to use a zigzag path on small areas or slopes that are not too steep.
- 2) **Parallel** – A second approach is to make a series of passes parallel to the crest of the dam, moving down the slope (Figure 4-3b). It is preferable to use parallel passes on larger slopes or on slopes that are steep because this method is less arduous.

Both techniques are acceptable methods for inspecting the dam slopes and crest. Whichever technique is used, the goal is to be able to see the entire area. Reaching this goal may require that you walk the area several times for dams with high embankments. At regular intervals, while walking the slope, inspectors should stop and look around for 360 degrees to check the alignment of the surface. Inspectors should double check the procedure to make sure that no areas or deficiencies have been overlooked. By stopping and looking around in this fashion, inspectors should be able to view the slope from different perspectives. Seeing the slope from various perspectives sometimes reveals a deficiency that might otherwise be undetected.

In addition, viewing the slope from a distance may also reveal anomalies such as distortions of the embankment surfaces and subtle changes in vegetation. Often these types of irregularities are not clear when viewing them close-up. Finally, viewing the downstream slope and toe area of the dam from a distance at a time of day when the angle of the sun is low can reveal wet areas, which become more visible because of the reflection of sunlight.

4.2.3 Embankment Groins

Inspectors should thoroughly inspect the areas where the abutments contact the embankment by walking these areas. These areas are called the groins; it's where the embankment toe intersects the existing ground surface. The groins are susceptible to surface runoff erosion, and seepage often develops along the downstream groins. The best approach to inspecting these areas is quite simple: Inspectors should walk down the left (or right) groin, and then walk up the groin on the other side of the dam. The same approach is used for both upstream and downstream groins. Inspectors should also check the toe of the embankment when examining the groin areas.

4.2.4 Dam Crest

Inspecting the dam crest is like inspecting the slopes. An inspector can use either a zigzag pattern or a parallel pattern to carry out the examination. Inspectors should walk the crest as many times as necessary to cover the entire area. Thorough coverage is required to ensure that no deficiencies go undetected. The important thing is to look at every square meter of the crest surface. Another helpful technique is to view the crest from different perspectives (Figure 4-4). Some deficiencies can be spotted close-up, while other deficiencies can be seen only from a distance.

When checking the alignment of the crest and any berms on the upstream and downstream slopes, inspectors can use a simple sighting technique to identify misalignments and other problems. An inspector should center his eyes along the line being viewed

and move from side to side to look at the line from several angles. The use of binoculars or a telephoto lens can help spot irregularities because they foreshorten distances and help highlight distortions.

The use of a reference line can also be of great help in sighting. Reference lines can be existing features such as guardrails, a row of posts, pavement stripes on the roadway running along the top of the dam, parapet walls, and permanent monuments that serve as horizontal or vertical control points along the surface of the dam. However, when using artificial reference lines, an inspector must make sure that the features have not been displaced by other causes, such as vehicles, lawn mowers, tractors, and vandalism. When sighting along the crest, an inspector needs to view the chosen reference line from several different perspectives. First, sight on a direct line; then move to either side. This sighting technique is also useful for detecting a change in the uniformity of the slope. The contact between the reservoir waterline and the upstream slope should parallel the alignment of the dam axis. In other words, the reservoir waterline should be a straight line if the dam has a straight axis. To check the alignment of the waterline, inspectors should stand at one end of the dam and sight along the waterline. Misalignment of the waterline may show a change in the uniformity of the slope.

4.3 What to Look For

Some of the more common conditions that may be encountered during visual inspection of the embankment include longitudinal and transverse cracking, desiccation cracking, depressions, settlement, slides, seepage, lack of protection from wave action, erosion, inappropriate vegetation, tree root penetration, poor maintenance, ponding water, animal burrows, and debris. Many of these concerns are interrelated and occur in conjunction or because of each other.

A dam inspector should visualize the worst-case conditions (i.e., the design storm is occurring) when looking for potential problem areas. For example, the maximum loads on roads and other structures, highest

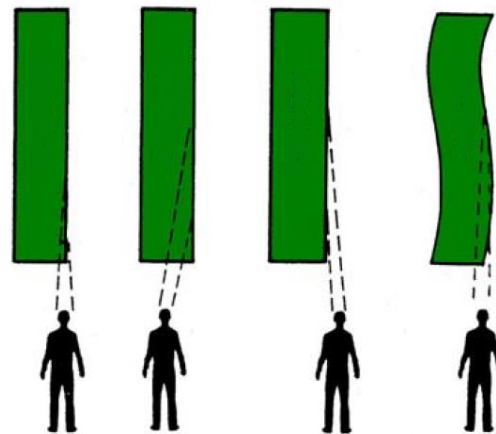


Figure 4-4. A helpful technique is to view the crest from different perspectives. The sketches on the left-hand side of the figure show sighting along a straight embankment, while the sketches on the right-hand side show sighting of a bowed embankment.

water levels in the reservoir, peak flow rates from the principal spillways, discharge through the auxiliary spillways, and winter icing conditions should be considered.

The dam's crest usually provides the primary access for visual inspection and maintenance. Because surface water will pond on the crest unless that surface is well maintained, this part of the dam may require regrading periodically. Problems found on the crest should not be graded over without determining the cause. When a questionable condition is found, it should be evaluated, and a qualified dam safety professional should be consulted if necessary. Quick corrective action applied to conditions requiring attention will extend the useful life of the dam and prevent costly repairs in the future.

The upstream slope needs a thorough visual inspection, because the slope protection, vegetation, debris, and reservoir water can hide problems. Anytime the reservoir is emptied, the slope should be thoroughly inspected for settlement areas, animal burrows, sinkholes, or slides. Also, the bottom of the impoundment should be inspected for sink holes or settlement anytime it is emptied.

The downstream slope is of particular importance during visual inspection because it is the area where evidence of developing problems appears most often. The downstream slope requires detailed visual inspection. Keeping this area free from vegetative growth that obscures an inspector's view is crucial. When cracks, slides or seepage are noted in this area, the cause should be determined, and corrective action should be recommended at once.

4.4 Cracks and Slides

Cracks and slides may signal serious problems within the embankment. Looking for and spotting cracks may be difficult, particularly if the embankment is covered with heavy brush or vegetation. An inspector needs to walk along the slope in such a way that all the cracks will be spotted. Embankment slides are usually easy to find.

Cracks on embankments are divided into three categories in this chapter: 1) longitudinal cracks, 2) transverse cracks, and 3) desiccation cracks. Cracks in the embankment are often the beginning of a slide and further weaken the soil strength by allowing more water to enter the embankment. To help distinguish drying (desiccation) cracks from other types of cracks, the ground surface next to the dam should be examined for similar cracking patterns. Cracks should always be taken seriously, and the cause of the cracking should be determined so that the correct remedy can be developed.

Cracks may be only a centimeter or two wide but 0.5 to 1.0 meters deep. Usually, a depth of more than 0.5 m means that a serious condition is present. Shallow cracks may be harmless desiccation cracks. All cracks over 0.3 m deep should be closely checked and evaluated.

Cracks may also be a sign of foundation movement or failure, the beginning of embankment failure, or a surface slide. For example, a 20-foot-long line of recently dislodged riprap along the upstream slope could indicate a crack underneath the riprap.

4.4.1 Longitudinal Cracks

Longitudinal cracking may be a sign of localized instability, differential settlement, foundation settlement, and movement between adjacent sections of the embankment. In recently built structures, longitudinal cracks may be a sign of inadequate compaction of the embankment during construction. This form of cracking can occur anywhere on an embankment.

Longitudinal cracking is characterized by a single crack or a close, parallel system of cracks along the crest or slope in a direction parallel to the length of the dam. These cracks, which are continuous over their length and are usually more than 0.3 m deep, can be differentiated from drying cracks which are typically intermittent, erratic in their pattern, shallow, narrow, and many. Longitudinal cracking usually signals the beginning of a slide or slough and may precede vertical displacement as the dam attempts to move to a position of greater stability (Figure 4-5). In this case, the crack usually develops into a scarp which forms during movement of unstable slopes. Vertical displacements on the crest are usually accompanied by displacements or bulging on the upstream or downstream faces of the dam.

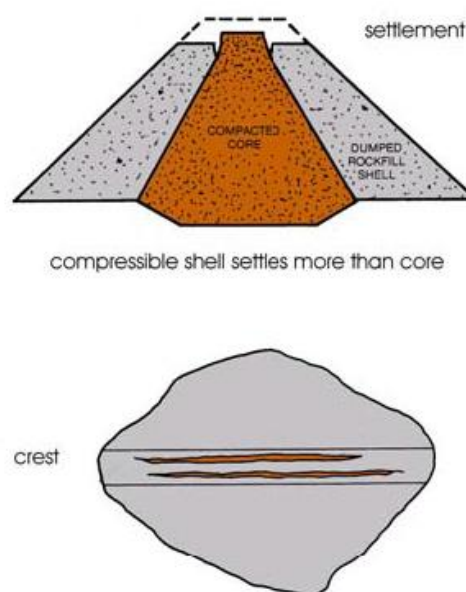


Figure 4-5. Longitudinal cracking caused by differential embankment settlement.

Longitudinal cracks can allow storm-water and reservoir water to enter the embankment. When water enters the embankment, the strength of the embankment material next to the crack may be reduced. The lower strength of the embankment material can lead to or accelerate slides and slope stability failure.

Longitudinal cracks usually get worse with time because of rainfall, seepage, and the decreasing strength of the embankment and foundation materials. When the soil is weakened sufficiently, or the ground below the crack becomes saturated, sloughing or sliding will occur. As the soil saturates, it becomes heavier, resulting in an increased tendency for the soil mass to move downward. Weakening and removal of foundation materials by water movement will also cause increased settlement of the embankment resulting in increased cracking.

If longitudinal cracking is found during a visual inspection, the following actions should be taken:

- Photograph and record the location, depth, length, width, and offset of each crack that has been discovered. Stakes should be placed at the ends of the cracks, and the distance between the stakes measured and recorded. Compare observations with earlier results.
- Closely monitor the crack for changes and scarping.
- Recommend proper corrective action be taken to repair or to replace the damaged slope or crest areas.
- Consult a qualified dam safety professional to decide the cause of the cracking if it is severe, or becomes progressively worse.

4.4.2 Transverse Cracks

Transverse cracking may be a sign of differential settlement or movement between adjacent segments within the embankment or the underlying foundation (Figure 4-6). Transverse cracking is usually a single crack or a close, parallel system of cracks which extend

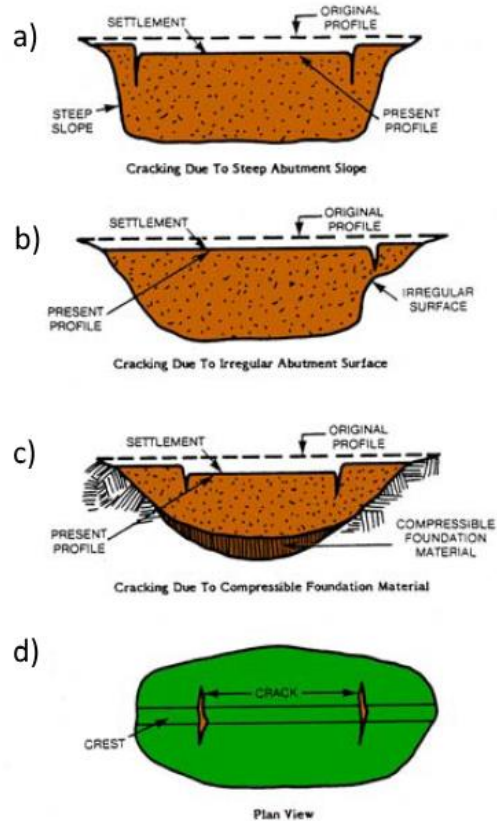


Figure 4-6. Transverse cracking caused by differential settlement within an embankment.

across the crest in a direction perpendicular to the length of the dam. This type of cracking is usually greater than 0.3 m in depth and can easily be distinguished from drying cracks. Transverse cracking poses a definite threat to the safety and integrity of the dam. If the crack should progress to a point below the reservoir water surface elevation, seepage could occur along the crack and through the embankment cross-section. This could evolve into a piping situation, and if not corrected, lead to breaching of the dam.

Transverse cracking often develops when compressible material overlies abutments consisting of steep or irregular rock, or when areas of compressible or erosive material are in the foundation. Soft or weathered rock formations in the foundation may collapse or erode from ground water action, leading to embankment settlement. Limestone is another potentially hazardous foundation material that can dissolve in groundwater, creating

voids that can lead to embankment settlement. For this reason, dams in karst areas may be particularly hazardous.

If transverse cracking is seen during a visual inspection, the following actions should be taken:

- Photograph and record location, depth, length, width, and offset of the cracks. Stakes should be placed at the ends of the cracks, and the distance between the stakes measured and recorded.
- Closely monitor the cracks for changes.
- Recommend corrective action be taken to repair or to replace the damaged slope or crest areas.
- Consult a qualified dam safety professional to figure out the cause of the cracking if it is severe or becomes progressively worse. Serious transverse cracking or repair operations usually require lowering the reservoir level.

4.4.3 Desiccation Cracks

Desiccation cracking is caused by the drying out and shrinking of certain types of embankment soils, usually highly plastic soils that contain a large percentage of clay. These types of cracks usually develop in a random, honeycomb pattern on the crest and the downstream slope (Figure 4-7). The cracks may be oriented longitudinally or transversely, or both. Desiccation cracking may also develop on the upstream slopes above the water level. Although not normally used in embankment construction, soils composed largely of silts will also display desiccation cracking if exposed to drying. As an example, desiccation cracking can be observed in “mud puddles” that completely dry out, leaving behind a series of cracks in the bottom of the puddle.

The worst desiccation cracking develops when a combination of the following two factors is present:

- 1) A hot, dry climate accompanied by extended periods in which the reservoir remains lowered or empty.



Figure 4-7. Desiccation cracks that form a honeycomb pattern.

- 2) The embankment is composed of highly plastic soil, such as clay.

Usually, desiccation cracking is not harmful unless it becomes severe. The major threat of severe desiccation cracking is that this type of cracking can contribute to the formation of gullies. Surface runoff erosion concentrating in the desiccation cracks or gullies can result in future damage to the dam. Also, heavy rains can fill up these cracks and cause portions of the embankment to become unstable and to slip along crack surfaces where the water has lowered the strength of the embankment material. Deep cracks that extend through the core can cause a breach of the dam when the reservoir rises, and the cracks fail to swell rapidly enough to reseal the area.

If desiccation cracking is spotted during a visual inspection, the following actions should be taken:

- Probe the more severe cracks to find their depth.
- Photograph and record the location, depth, length, and width of any severe cracks discovered.
- Compare the measurement of the crack dimensions with past measurements to determine if the condition is worsening.
- Recommend corrective action be taken to repair or to replace the damaged slope or crest areas. Usually, repairs by sealing and grading are adequate.

- Consult a qualified dam safety professional to determine the cause of the cracking if it is severe or gets progressively worse.

4.4.4 Embankment Slides

Embankment slides have various names including displacements, slumps, slips, and sloughs and can be grouped into two broad categories: shallow slides and deep-seated slides. Shallow slides are called sloughs, or sloughing. Slides develop when the strength of the soil in the embankment is less than the forces that cause slope failure. Steep embankment slopes, poor soil compaction, improper soil composition, excessive water in the ground, and seepage contribute to slides.

Shallow embankment slides on the upstream slope are often the result of an overly steep slope and/or poorly compacted soils. These conditions can be aggravated by a rapid lowering of the reservoir. Shallow slides on the upstream slope usually pose no immediate threat to the integrity of the dam. However, shallow slides may lead to the obstruction of water conveyance structure inlets and larger, deep-seated slides.

Shallow embankment slides on the downstream slope are caused by an overly steep slope or poorly compacted soils. In addition, these slides may also be the result of a loss of strength in the embankment material. A loss of strength in the embankment material can be the result of saturation of the slope from either seepage or surface runoff. Additional loads from snow banks or structures can aggravate the condition. The dam owners or inspectors should consult a qualified dam safety professional if they are unsure whether the slide presents a serious threat to the integrity of the dam.

Deep-seated embankment slides (Figure 4-8) are serious threats to the safety of a dam and may be recognized by the presence of a well-defined scarp or bulging on the slope or at the toe. Arc-shaped cracks on the slope are usually indications that a slide is beginning. This type of crack may develop into a large scarp at the top of the slide.

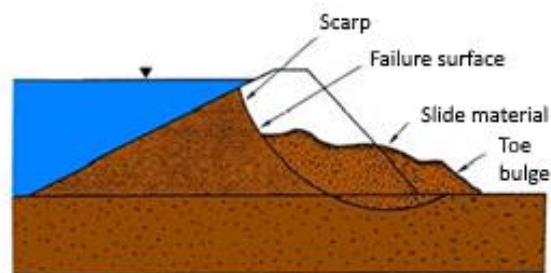


Figure 4-8. A deep-seated embankment slide is a serious threat to the safety of a dam.

Bulging is usually associated with the lateral spreading of the dam or with embankment slides (Figure 4-9). Bulging because of lateral deformation is accompanied by the settlement of the crest and a potential loss in dam freeboard. Bulging is most evident at the toe of the dam. If an inspector suspects a loss of freeboard, a survey of the crest should be performed to verify if there has been a loss of freeboard. The area above a bulge should be checked for other indicators of instability such as cracks and scarps. However, not all bulges suggest a stability problem. When the dam was constructed, it may not have been uniformly graded by the dozer or grader operator, so there may be bulges in the embankment that were formed during construction. Inspectors should figure out the cause of the bulging and recommend a course of action. Bulging associated with slides is a more severe problem. If bulging associated with cracks or scarps is discovered, a qualified dam safety professional should be contacted at once.

Embankment slides are usually easy to spot and require immediate evaluation by a geotechnical engineer if they are large or are continuing to show movement. However, slides may be difficult to spot if a scarp has not developed. Their appearance may be

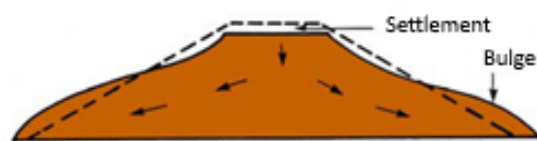


Figure 4-9. An illustration of bulging and associated crest settlement.

subtle because there may be only a small amount of settlement or bulging out from the intended slope. A good familiarity with how the slope looked at the end of construction will help detect slides.

Most embankment slides have early warning signs that allow their detection. They usually develop over a brief period, beginning with some form of surface cracking, followed by measurable vertical displacement and scarping, and potentially ending in complete failure of the embankment or slope. A bulge in the embankment and vertical displacement at a crack in the embankment are usually signs of sliding. Stormwater falling onto or running into the slide area may make conditions worse and accelerate the instability of the slope. Longitudinal and arc-shaped cracks are usually a symptom of impending slides.

If an embankment slide or bulge is detected during a visual field inspection, the following actions should be taken:

- Photograph and record the location, depth, length, width, and height of the scarp for each slide or bulge found. Stakes should be placed at the ends of the scarp, and the distance between the stakes measured and recorded.
 - Look for any surrounding cracks, especially uphill from the slide.
 - Closely inspect the area above a bulge for cracking or scarps which indicate that a slide is probably the cause. Probe the bulge to figure out if the material is extremely moist or soft. Excessive moisture or softness is further evidence that that a slide is a cause.
 - Look for evidence of seepage or saturated soils in or below the slide. Probe the entire area to find the condition of the surface material.
 - Closely monitor the slide for changes.
 - Consult a geotechnical engineer to investigate the cause of the slide if it is severe.
 - Recommend proper corrective action be taken to repair or to replace the damaged slope or crest areas.
- When deep-seated slides occur, the reservoir water level will need to be lowered to prevent breaching of the dam.

4.5 Depressions

Depressions can be small and inconsequential, or they can be large and endanger the dam. Sinkholes are a serious type of depression and are cause for alarm. An effective way of distinguishing between minor depressions and sinkholes is to look at their profiles. Minor depressions have gently sloping, bowl-like sides, while sinkholes usually have steep, bucket-like sides. Some areas that appear to be depressions may be the result of improper final grading following construction. Settlement on the crest is a serious form of depression that can result in lowering of the embankment, creating a potential for overtopping. Although most minor depressions are not an immediate danger to the dam, they may be early indicators of more severe problems that are developing. Depressions may also result in water ponding on the crest of the embankment which may lead to stability problems because of soil saturation in the embankment.

Depressions can be serious safety concerns and are typically caused by:

- Localized settlement in the embankment or foundation.
- Embankment spreading in the upstream and/or downstream directions This type of spreading may result in a loss of freeboard or reservoir capacity and can cause overtopping of the dam.
- Erosion by wave action of the upstream slope that removes embankment fines or bedding from beneath riprap may form a depression as the riprap settles into the vacated space. This may only appear on the upstream slope or may spread to the crest of the dam if the damage is severe.
- Internal erosion (piping) that may cause surface soils to collapse into the voids created by the piping, creating sinkholes.
- The collapse of soils into animal burrows can create depressions or sinkholes.

Depressions and other misalignments in the crest (and embankment slopes) often can be detected by sighting along fixed points. Inspectors should sight and take photographs along guardrails, parapet walls, or pavement striping. Some apparent misalignment may be caused by the slightly varied placement of the fixed points. For this reason, irregularities should be evaluated over time to verify suspected movement. Sighting of irregularities is made easier by surveying permanent monuments along the crest to calculate the exact location and the extent of misalignment. A record of survey measurements also can show the rate at which movement is occurring.

Sinkholes are a serious type of depression that can result in hazardous embankment safety conditions. Sinkholes are formed when the removal of some embankment or foundation soils has caused the overlying material to collapse into the resulting void (Figure 4-10). The presence of a sinkhole may be a sign that material has been transported out of the dam or foundation through the process of piping. In addition, animal burrows, and flowing water under pipes, walls, and slabs can contribute to the formation of sinkholes. The decomposition of embedded wood or other vegetative matter in the embankment also can cause sinkholes. If the embankment depressions or settlement progresses to a level below the normal pool elevation, the reservoir may overtop the embankment, resulting in breaching or total embankment failure. The settlement also reduces the storage capacity and freeboard of the dam which could cause overtopping, breaching, or failure by large floods.

If depressions are found during a visual inspection, the following actions should be taken:

- Photograph and record the location, size, and depth of the depression.
- Probe the floor of the depression to decide whether there is an underlying void. An underlying void indicates a sinkhole.
- Frequently check the depression to keep track of its development.

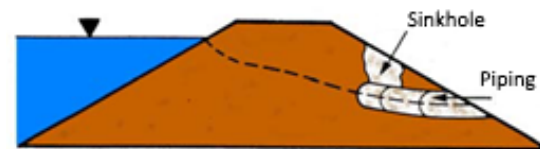


Figure 4-10. A sinkhole caused by a collapse into an animal burrow.

- Consult a qualified dam safety professional to figure out the cause of the depression if it is severe, or if it progressively worsens.
- Recommend proper corrective action be taken to repair or to replace the damaged slope or crest areas.

4.6 Inadequate Slope Protection

Slope protection is designed to prevent erosion of the embankment slopes, crest, and groin areas. Inadequate slope protection usually results in deterioration of the embankment from erosion, and in the worst cases, can lead to dam failure. Inspectors should look for inadequate slope protection, including eroded and displaced materials, and lack of vegetation during every visual inspection.

The two primary types of slope protection used on embankment dams include a vegetative cover (grass) and riprap (rock). Grass cover is usually applied to most embankment surfaces, while riprap is often used on the shoreline of the upstream slope. Soil cement, concrete, asphalt, articulated concrete blocks, are alternative protective covers. The kind of slope protection selected depends upon economics, how the dam is used, and the prevailing conditions found at the site. A healthy growth of grass on an embankment provides excellent protection against erosion caused by rainfall and runoff. Deep-rooted grass that can tolerate repeated wetting and drying cycles should be used on embankments.

A lack of vegetative cover or insufficient vegetative cover will result in rapid deterioration of the embankment from erosion. A lack of riprap or improperly designed riprap along the shoreline can cause erosion of the shore

soils if riprap is needed to protect the ground against wave action. It should be noted that not all dams will require riprap shoreline protection.

Riprap should be properly sized and placed to offer protection from erosion caused by wind or wave action, surface runoff erosion, and scour resulting from the wind. Properly designed upstream riprap slope protection is made up of at least two layers of material: (1) an inner filter layer or bedding to keep the underlying soil from washing away; and (2) an outer rock layer to prevent erosion. The inner filter layer could be sand or fine aggregate, or a geotextile.

When the protective riprap cover is removed, the ground beneath the riprap is exposed to erosion damage. Undercutting by wave action, slides, and slope failure can lead to failure of the upstream slope, a spillway channel, a plunge pool, or, if erosion continues unchecked, the breaching of the embankment (Figure 4-11). Inspectors should look closely for signs of soil erosion and undercut in all riprap areas. If the slope protection is found to be inadequate, inspectors should:

- Photograph and record the location, size, and extent of the area of damaged riprap.
- Determine the cause of the problem, if possible.
- Recommend corrective action be taken to repair or to replace the damaged areas. Monitor the area if immediate repairs are not feasible (e.g., the wrong season for planting grass).

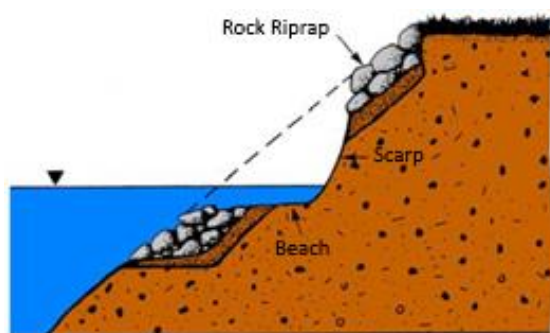


Figure 4-11. Wave action can remove riprap if it is not properly sized and installed. The illustration shows beaching and formation of

4.7 Weathering and Erosion

Erosion is a natural process, and its constant forces will eventually wear down almost any surface or structure. Consequently, the dam inspector should always be on the lookout for signs and causes of erosion so that corrective action can be applied to halt its progression. Surface runoff erosion is one of the most common problems on embankment structures. If not corrected, surface erosion can become a more severe problem. An inspector should make sure that the slope protection is adequate to prevent erosion by looking for beaching, scarping, and degrading of the slope protection, as well as erosion of the dam soil materials.

The worst damage from surface runoff is manifested by the development of deep erosion gullies on the slopes and groins of both upstream and downstream slopes. Severe gullies can cause breaching of the crest or shorten the seepage path through the dam, leading to piping. Gullies can develop from poor grading or sloping of the crest that leads to improper drainage, causing surface water to collect and to run off at the low points along the upstream and downstream shoulders. Gullies resulting from this type of runoff eventually can reduce the cross-sectional area of the dam.

Bald areas or areas where the protective cover is sparse are more susceptible to surface runoff erosion problems. On the upstream slope, erosion may undermine the riprap and cause it to settle. Settlement of the riprap may lead to the eventual degradation of the slope itself.

Shallow gullies formed by soil erosion that are less than 15 centimeters deep, which are known as rills, are common on many earth embankments. The formation of rills is hard to stop, especially on long slopes. Stormwater runoff will tend to concentrate at one or more locations and form preferred flow paths, resulting in surface soil erosion in the shape of rills and gullies. Shallow rills usually do not present a safety concern, but they should be watched and repaired if they

worsen. These conditions should be inspected following large or prolonged storms. Shallow rills will often have grass growing in them. If the vegetation has been eroded and removed from the rills exposing the bare soil, the rills will increase in size every time storm-water runoff flows through them. Repair of rills may do more harm than good to the slopes when trying to repair minor erosion, so sound judgment will be needed when recommending and scheduling repairs of this type of damage (e.g., do not perform repairs when the slopes are saturated, or when the damage is minor and does not show signs of accelerated damage).

Even the best-designed erosion protection will usually experience degradation over time. Degraded riprap or other types of embankment protection should be watched. If evidence shows that considerable damage to the embankment is occurring, degraded slope protection must be repaired or replaced.

The constant action of waves on the upstream slope may result in beaching, scarping, and degrading of the slope protection, including riprap. Unless measures are taken to maintain adequate slope protection, wave action may begin to erode the embankment material.

Beaching is the removal of a part of the upstream slope of the embankment by wave action. Figure 4-11 shows the effects of erosion and beaching on the upstream slope of a dam. When beaching occurs, embankment material is deposited farther down the slope. In this extreme form of erosion, the slope protection (i.e., riprap or vegetative cover) and underlying material are removed. A flat beach area with a steep back slope, or scarp, is formed. Scarps should be monitored and repaired if conditions become serious.

Severe beaching could reduce the width and the height of the embankment, leading to increased seepage, instability, or overtopping of the dam. Riprap installations in areas exposed to many freeze-thaw cycles or high winds are most likely to experience problems.

Inspectors should be alert for riprap problems if the dam is exposed to these conditions.

Adequate erosion protection is also required along the contact between the embankment and the abutments. Runoff from rainfall concentrates in these groin areas and can reach erosive velocities because of the steep slopes. Berms on the upstream or downstream face that collect surface water and empty into the groins add to the runoff volume. Inspectors should examine these areas closely.

Erosion next to groins results from improper construction or design, where the finished flow line of the groin is too high with respect to adjacent ground. This condition prevents all or much of the runoff water from entering the groin. The flow concentrates alongside the groin, erodes a gully, and may eventually undermine the lining in the groin. When examining the groins for erosion, inspectors should make sure that: 1) the channel in the groin has adequate capacity; 2) adequate protection and a satisfactory filter have been provided; 3) surface runoff can enter the groin channel; and, 4) its outlet is well-protected from erosion.

Several exceptional circumstances can contribute to or initiate surface erosion of the crest and downstream slope. In some areas, livestock may create trails on the embankment which can damage the slope's vegetative cover. The passage of vehicles can produce sunken tracks or grooves (ruts) in the crest and can damage the slope protection. Inspectors should be aware of any unique problems that may be occurring and past problems that were noted on earlier dam inspections.

During the visual inspection, inspectors should:

- Make sure that the slopes and crest protection are adequate to prevent erosion. Bald areas or regions where the surface protection is sparse are more susceptible to surface runoff problems.

- Look for beaching, scarping, and degradation of riprap or other materials used on the upstream slopes.
- Look for gullies, ruts, or other signs of surface runoff erosion. Be sure to check the low points along the upstream and downstream shoulders and groins because surface runoff can concentrate in these areas.
- Check for any unique problems, such as livestock or recreational vehicles that may be contributing to erosion.

If weathering and erosion are noticed, inspectors should:

- Record the findings and photograph the area.
- Determine the extent, severity, and cause of the damage. Measure gullies, rills, and other erosion damage so that its progression can be checked if necessary.
- Recommend that corrective action is taken to repair the areas damaged by surface runoff and that measures are adopted to prevent more serious problems.
- If shorelines need to be repaired, or extensive embankment excavation is required, the reservoir level may need to be lowered.
- Consult a qualified dam safety professional if necessary.

4.8 Inappropriate Vegetative Growth

Inappropriate vegetative growth – which includes insufficient vegetation, excessive vegetative growth, and deep-rooted vegetation – is another common embankment problem. Insufficient vegetation exposes the embankment soil which can lead to accelerated erosion. The insufficient vegetative cover may be a result of soil conditions, environmental conditions, or damage arising from traffic on the embankment. Soil conditions usually include the lack of sufficient plant nutrients or poor soil composition. Poor soil conditions can be corrected in most cases. Environmental conditions are uncontrollable and include

extreme heat and dry weather, excessive rainfall, and high winds that can remove fine-grained soils. Repeated vehicular and animal traffic can destroy the grass on embankments, leaving bare soil roadways or paths which are susceptible to accelerated erosion if left uncorrected.

Insufficient vegetation on the embankment slopes can progress to serious problems if left uncorrected for extended periods of time. These conditions should be recorded during a visual inspection along with recommendations for corrective action. The recommendations should also include a proposed timeframe for completing the repairs.

Excessive vegetation is a problem wherever it occurs on an embankment dam. Excessive vegetation can obscure large sections of the dam which hinders visual inspection. Problems that threaten the integrity of the dam can develop and go undetected if they are obscured by vegetation. Excessive vegetation can also impede access to the dam and surrounding areas. Limited access is an obvious problem both for visual inspection and maintenance and especially during emergency situations when access is crucial. Excessive vegetation can also create an attractive habitat for rodents and burrowing animals which pose a threat to embankment dams by digging tunnels that become potential seepage paths.

There should be no vegetation in the riprap on the upstream slope. Vegetation in the riprap promotes displacement and degradation of the slope protection. Vegetative growth should be controlled by periodic mowing or other means. No trees or shrubs should be allowed to grow on any embankment surfaces, or within 8 meters of the abutment contacts. Grass cover should always be kept less than 30 cm high.

Although a healthy cover of grass is desirable as slope protection, the growth of deep-rooted vegetation, such as large shrubs and trees, is undesirable. Large trees could be blown over and uprooted during a storm. The resulting cavity left by the root system could reduce the embankment top elevation,

breach the dam or shorten the seepage path and initiate piping. Accelerated soil erosion will also develop in the cavity left by an uprooted tree because of the exposed soil surfaces. The cavity left by the uprooting of a tree should be repaired immediately. The method of cavity repair will depend on the size of the tree and the location of the tree on the embankment.

Root systems associated with deep-rooted vegetation (trees, shrubs) develop and penetrate the dam's cross section, causing damage to embankment and spillway structures. When the vegetation dies, the decaying root system can form paths for seepage and cause piping to occur. Even healthy root systems of large vegetation can pose a threat by creating seepage paths which eventually can lead to internal erosion and threaten the integrity of the embankment. Trees and shrubs more than 0.5 m in height are undesirable growing on or next to embankment dams and should be cut down or pulled out before they reach a critical size. When and how to remove well-developed trees and root systems that are already in place on the dam depends on the size and location of the tree. If large trees have been cut down, but the stumps and/or root system have not been removed, carefully inspect the areas where the trees were for signs of seepage. The roots that are left behind may rot over time resulting in potential seepage paths.

During the visual inspection, inspectors should:

- Look for excessive and deep-rooted vegetation on all areas of the dam and within 8 m of the abutment contacts.
- Look for trees and brush in the spillways or near conduits.
- Look for insufficient grass covering and exposed areas on earth embankments.
- Look for excessive grass growth; grass should be mowed regularly and kept below 30 centimeters in height.
- Make sure that there is no vegetation growing in the riprap on the upstream slope.

- Check for signs of seepage around any remaining stumps or decaying root systems on the downstream slope or toe area.

If areas where vegetative cover is inappropriate or inadequate are found, inspectors should:

- Photograph the area and record the findings.
- Note the size, location, and extent of the areas in question.
- Recommend that corrective action is taken to repair inadequate vegetation, or to eliminate inappropriate vegetation and that measures are adopted to prevent the future growth of undesirable vegetation.
- Consult a qualified dam safety professional if help is needed.

4.9 Debris

The collection of debris on and around the dam is usually not an immediate danger to the integrity of the dam. However, unattended debris can lead to serious problems. The buildup of brush and logs on the dam can obscure the upstream slope and can prevent adequate visual inspection. Debris can accelerate the process of degradation of the riprap or other slope protection by impact from wave action.

Debris can clog or block spillway and outlet systems, resulting in potential dam overtopping hazards. Woody debris can become waterlogged and sink, blocking outlet works, inlet, or spillway inlets. Floating debris can also clog trash racks on spillways with riser conduits. The blocking of these inlet structures can cause overtopping of the dam in case of a flood. Certain animals, such as large semiaquatic rodents, can contribute to the accumulation of debris in and around the dam. Removal of debris is usually an easy task. If inspectors find debris in and around a dam, they should:

- Determine the cause of the debris, and, photograph, record, and report observations.

- Recommend that proper corrective action is taken to remove the debris and that measures are taken to prevent future accumulations.

4.10 Burrowing Animals

Animal burrows can be dangerous to the structural integrity of the dam because they may weaken the embankment and can create pathways for seepage (FEMA 2005c). Large burrowing animals make nests and passageways in soil, including many dam embankments. The animal passageways can lead to piping in the embankment soils when they connect the reservoir to the downstream slope or penetrate the dam's core. Shallow burrows or burrows that are confined to one side of the embankment may be less dangerous than these deep or connective passageways. If shallow burrows are so prevalent that they honeycomb an embankment, the integrity of the embankment is suspect. A qualified dam safety professional should be consulted for severe cases to evaluate the embankment condition and suggest corrective measures. If burrowing animals are present, inspectors should photograph the area and record their findings, and recommend that measures be taken before acute damage occurs to the dam. Eradication or removal is usually the recommended course of action.

Small burrowing animals such as crawfish, mice, and moles are also common on earth embankments. These animals live in small burrows that usually do not pose a threat to dam safety. Crawfish dig vertical holes from the ground surface to a level below the groundwater surface, or phreatic surface, in the embankment. These holes are small and are usually vertical only, so they normally do not create the potential for lateral water seepage through the embankment. However, in some instances, their holes have been found to intercept the phreatic surface on the downstream embankment slope, resulting in concentrated water seepage from the dam. In these cases, removal of the crawfish and repair of the embankment may be required.

During the visual examination, inspectors should:

- Look for signs of large and small burrowing animals on earthfill embankment sections of dams
- Photograph and record signs of animal presence and damage they have caused.
- Recommend that proper corrective action is taken to remove the animals from the dam and to repair the damage.

4.11 Seepage

Water will flow through or under every embankment because all earth materials are permeable. The passage of water through or under an embankment is known as seepage. Seepage quantities and rates increase as the depth of the water in the reservoir increases because of the greater pressure upstream of the embankment. Downstream groin areas should always be inspected closely for signs of seepage. Seepage can also occur along the contact between the embankment and a conduit spillway, drain, or another appurtenance (Figure 4-12. Areas at an embankment dam where seepage is commonly observed.).

Seepage becomes a problem when embankment or foundation materials are moved by the water flow, or when excessive pressure builds up in the dam or its foundation. Problem seepage is often referred to as uncontrolled seepage. Excessive seepage and pressure can result in embankment slides and instability. Slides and other embankment prob-

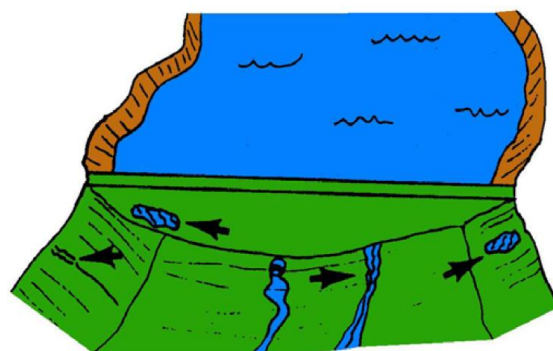


Figure 4-12. Areas at an embankment dam where seepage is commonly observed.

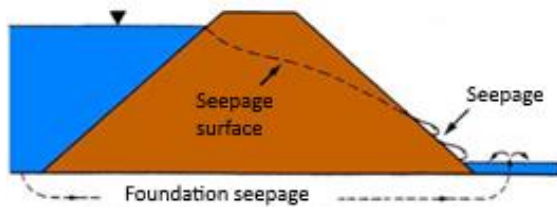


Figure 4-14. Seepage may occur through the embankment or the foundation.

lems are often a direct consequence of seepage that has saturated and weakened the embankment soils. Problem seepage is a grave concern and should be corrected before embankment structural damage occurs.

4.11.1 Types and Location of Seepage

Seepage can emerge anywhere on the downstream face, beyond the toe, or on the downstream abutments at elevations below normal pool (Figure 4-14). Seepage may vary in appearance from a soft, wet area to a flowing spring. It may show up first as only an area where the vegetation is more lush and darker green. Slides in the embankment or an abutment may be the result of seepage causing soil saturation or excessive pressures in the soil pores (Figure 4-13).

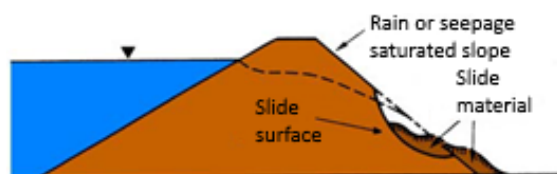


Figure 4-13. Uncontrolled seepage may result in embankment slides and slope failure.

Some water will seep from the reservoir through the foundation at most dams. Where it is not intercepted by a subsurface drain, the seepage will emerge downstream from or at the toe of the embankment. If the seepage forces are large enough, the soil will be eroded from the foundation and be deposited in the shape of a cone around the outlet, which is known as a boil. Prompt expert advice should be sought if boils appear.

Seepage flow which is muddy and carrying soil particles is evidence of piping, and complete failure could occur soon afterwards if it is serious. Piping can happen along a spillway and other conduits through the embankment, and these areas should be closely inspected. Sinkholes that develop on the embankment may be signs that piping has begun (Figure 4-10), and could be followed by a whirlpool in the lake surface along the upstream embankment (Figure 4-15) and then a rapid and complete failure of the dam. Emergency procedures, including downstream evacuation, may have to be implemented if this condition is noted.

A slow continuous drop in the normal lake level could be the result of evaporation or small controlled releases. However, an inexplicable continuous recession in pool level, or especially, a sudden drop in water level is usually a sign that serious problems exist and immediate attention is required. The entire embankment, the appurtenances, and the area downstream should be inspected for signs of increased seepage or flowing water. This condition may be a sign that a genuine problem exists that requires close and frequent monitoring.

Uncontrolled seepage is a leading cause of embankment dam failure. Seepage problems can be divided into two categories based on the type of problem it causes: stability problems, and piping problems. Seepage causes stability problems when high water pressure and saturation in the embankments



Figure 4-15. Photograph of a whirlpool along the upstream slope of an embankment dam.

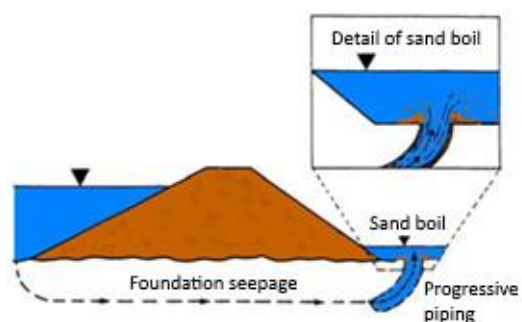


Figure 4-16. Illustration of progressive piping in the foundation of an embankment dam.

and foundations cause the earth materials to lose strength. If uncontrolled seepage emerges on the lower downstream slope, the seepage will usually cause sloughing or massive slides. If seepage is concentrated through materials such as sands or cohesionless silts, the force of the flowing water can start to remove material at the exit point, and cause progressive erosion known as piping.

Piping usually starts at or near the downstream toe with the removal of the soil material at the seepage exit, or outlet. A sand boil may develop at the seepage outlet if the material being eroded is coarse silt or sand (Figure 4-16). However, not all piping creates sand boils. As piping progresses, soil erosion continues upstream, eroding a void space, or pipe, through which the water flows. Erosion usually continues until the pipe extends all the way to the reservoir or another source of water. Severe piping problems can also occur when seepage moves embankment material into voids in rock foundations or rock fill portions of the dam.

It can be difficult to determine the source of seepage, because the exit may be the only visible sign. It may not be clear whether the water is flowing through the embankment or under it. Seepage may originate in the bottom of the reservoir, upstream of the embankment, and travel through porous soil strata in the foundation of the dam.

Some seepage is difficult to detect because nothing is visible until the embankment starts to collapse, or until a vortex appears in the reservoir. A vortex is a rotational

lake surface disturbance which could appear if water is rapidly conveyed through a seepage path or pipe. Formation of a vortex associated with significant seepage or piping through an embankment is a sign of a severe problem that needs to be resolved at once.

Seepage can vary in appearance and location. Seepage may appear as a wet area, as a flowing spring, or as a sand boil as described above. Vegetation is an excellent indicator of seepage. Areas with water-loving vegetation, such as cattails, reeds, and mosses, should be checked for seepage. Areas should also be examined where the vegetative cover appears to be greener or more lush than surrounding areas. Viewing the downstream slope from a distance is sometimes helpful in detecting subtle changes in vegetation. A distinct line of vegetation shows the intersection of the seepage line with the slope.

The contacts between the downstream slope and the abutments (or groins) are particularly prone to seepage because the embankment fill near the abutments is often less dense than other parts of the embankment, and therefore less watertight. The fill near abutments often less dense than elsewhere in an embankment because compaction is difficult along the embankment/abutment interface. Also, improperly sealed porous abutment rock can introduce abutment seepage into and along the embankment. Seepage in the groins may be groundwater from the abutments or valley walls and not seepage from the reservoir. Seepage that is orange in color or has an oily surface sheen shows the presence of dissolved iron in the water. This is a common condition of groundwater that has been in contact with iron-bearing soils. The orange coloration is from iron oxide which develops after the groundwater is exposed to the air, causing the dissolved iron to oxidize (rust) and settle out of the water. The orange coloration is from deposits of iron oxide on the ground and is not orange water.

The downstream embankment toe is also prone to seepage, especially where it contacts the natural ground. This area has the greatest amount of water pressure and is most likely to develop seepages. When seepage occurs at

the toe of an earthfill embankment, a slide may result along the downstream embankment slope. Saturated embankment toes can cause catastrophic slope failures. Proper treatment of the foundation is crucial during the embankment construction to control seepage.

Difficulties with soil compaction around conveyance structures like outlet works, spillway conduits, vertical walls, or penstocks make these areas more susceptible to uncontrolled seepage problems. Seepage exiting from around conveyance structures is particularly alarming because it may also be a sign that there is a crack or opening in the structure that is allowing reservoir water under pressure into the embankment. Rapid erosion and an eventual breaching of the dam can result from seepage around conduits. This type of seepage is excessive and will continue to erode the soils around the conduit.

Seepage along and under spillway conduits can find its way into the conduits, eventually eroding and deteriorating the conduit itself, as well as removing soil and bedding material from around the conduit. The conduit may settle or collapse if enough soil is piped out from under the structure. This type of seepage can be best observed when reservoir levels are below the spillway crest. In this situation, water will typically be coming out of the spillway conduit but will not be entering it from the inlet of the spillway in the reservoir. Many times, sediment, or deposited soils, will be visible within or at the outlet of the conduit. High reservoir water levels will aggravate this condition.

Another usual symptom of seepage and piping along the conduit is settlement and depressions above the conduit, particularly within the conduit trench. Again, this is the result of the removal of soil from around the conduit, allowing it to be replaced by surface soils which fall into the voids created by the piping condition.

Seepage can be caused by deep-rooted vegetation on embankments, such as trees. Tree roots can penetrate the embankment

and create passageways for water. Seepage along root systems will usually start off at a slow rate and get progressively greater with time. This is another example of the importance of early detection of seepages. As discussed previously in this chapter, up-rooted trees can also cause seepage problems.

Seepage from rock cuts on the abutments or the floor of the dam can create several potentially unsafe conditions. Inspectors should evaluate the rate of seepage, correspondence of seepage rates to reservoir level, staining, and turbidity of seepage to fully understand the problem. Seepage can create excess hydrostatic pressure, weaken the overall strength of the abutment or foundation, and produce increasingly large channels in the soil materials for water flow. Openings can enlarge sufficiently to cause abutment or foundation movement or collapse. Stains from seepage water indicate solutioning of minerals which may reduce the shearing strength of the rock materials and cause rock consolidation. An inspector may want to take samples of the seepage so that the minerals can be identified. Inspectors should also check the geologic data for evidence of deposits of limestone or other rock especially subject to solutioning that may underlie competent rock. Turbid flow indicates that internal erosion or piping is occurring. Inspectors should check the construction records to see if rock walls and slopes were grouted to control seepage. If grouting was not done in the past, this procedure might be able to reduce the seepage. If prior grouting proved inadequate to prevent or control seepage, a qualified dam safety professional should examine probable causes and sources for the seepage and evaluate corrective actions.

Seepage problems may worsen rapidly after they first appear. The location, quantity, and flow rate of all seepage should be recorded at the exit points. Recent precipitation events that may affect the appearance and amount of seepage should also be noted and recorded.

During a visual examination, inspectors should:

- Carefully inspect all the areas that are prone to seepage, including downstream embankment slopes, embankment toe, the area downstream of the toe, the embankment groins, and along the spillways.
- Look for all visual signs of seepage, including wet areas, excessive vegetative growth, lush green grass, lowered reservoir pool levels, piping, boils, sinkholes, flow into the discharge conduit from the soil, flow out of the discharge conduit into the ground, and embankment slides.

If seepage is discovered during a visual review, inspectors should:

- Record the findings and photograph the area. Notes, sketches, and photographs are useful in documenting and evaluating seepage problems.
- Determine the extent, severity, and cause of the seepage. Measure and photograph any damage caused by the seepage so that its progression can be monitored if necessary.
- If seepage is found, it should always be measured on a regular and frequent basis.
- The seepage should be checked for turbidity which would show the presence of soil in the water.
- Recommend that corrective action is taken to control the seepage.
- Recommend that corrective action is taken to repair the areas damaged by seepage and that measures are adopted to prevent more serious problems.
- If extensive embankment excavation is required, the reservoir level may need to be lowered.
- Consult a qualified dam safety professional if necessary.

4.11.2 Monitoring Seepage

Seepage may be or may become a severe problem and should always be monitored, regardless of the location, extent, or type of seepage present. Different monitoring proce-

dures are available depending on the condition. Part 2 of the Dam Inspection Manual describes instrumentation and monitoring of seepage in more detail.

The amount of seepage usually correlates with the water-surface elevation in the reservoir. As the water level rises, the seepage flow rate increases. Any changes in seepage flow rate which deviate from past seepage history are cause for concern. Recording seepage flow rates and reservoir levels will help assess a dam's seepage problems.

Seepage may discharge from the embankment at a single place, at several locations, or across a broad area. Discharge from a small area can often be easily measured and used for future comparison. The flow rate can be converted to a quantity of flow over a given period, such as a day, a week, or a month. These estimates can be used to determine if the embankment and/or foundation may be damaged from the flows.

Seepage on the embankment slopes, groins, or at the toe may occur over a large area which does not lend itself to measurement in terms of flow rate and quantity. In these cases, the seepage may be measured best by the width and length of the affected area, or as a qualitative judgment of the physical appearance of the seepage area. Alternately, a dike, pipe or another conveyance device could be installed on the embankment to concentrate the flows and make measurement easier. If a slide has developed as is often the case, the dimensions of the slide can be measured and recorded. General descriptions of the amount of flow and degree of vegetative growth are also helpful. For example, seepage can be described as visibly flowing on the ground surface, or as a wet spot with standing water puddles. If all the seepages flow to a single downstream channel or ditch, the flow rate may be estimated at that point.

If a sand boil or piping exit is discovered, inspectors should:

- Photograph and record the size and depth of the exit, or outlet opening.

- Photograph and record the size of the deposited material if it is a sand boil.
- Monitor the flow rate, if possible. The flow rate may be difficult to ascertain if the pipe outlet or sand boil is under water.
- Probe the outlet opening for depth and soil composition and consistency.
- Make sure that all sand boils are evaluated by a qualified dam safety professional so that the right remedial action can be taken.

Sometimes placing sandbags around the boil to increase the depth of water (head) over the boil will prevent the continued growth of the boil. Another temporary repair is to place a graded filter over the outlet opening to prevent more soil from being carried out of the pipe or boil.

In some cases, a dye test (using an approved, environmentally safe dye) can be used to determine whether or not the reservoir is the source of seepage. A dye test is not a routine procedure, is not always applicable, and may be difficult to administer. The origin of the seepage path must be in the reservoir so that the dye can be placed in the water near the area where water is entering the seep. The length of time it takes to conduct a test may vary because the dye may take different amounts of time to penetrate the embankment or foundation. In most cases, records of seepage volumes that correlate with pool elevations or comparative water sampling and testing are needed to show that seepage comes from the reservoir.

Weirs, flumes, and dikes can be installed to measure seepage, especially seepage exiting from the embankment or foundation at random point sources. When properly calibrated and kept free of silt and vegetation, weirs and flumes can measure seepage accurately. These devices can also be used downstream of general seepage areas where the water flows into a ditch or channel. Weirs and flumes that are silted-in may indicate that the embankment or foundation material is being piped out of the dam, or sediment from

surrounding surface runoff erosion is collecting in the structure. If weirs and flumes become silted-in, the situation should be carefully evaluated to determine the cause of the siltation. Dikes can be installed across a channel or ditch with a pipe installed to measure flow.

Many toe drains have collector pipes that discharge the embankment and foundation seepage at accessible locations. Before conducting a visual inspection of an embankment dam that has toe drains, inspectors should review the site plan to determine the location of the toe drains and outfalls. Previous data on both the reservoir level and flow rate from the drain(s) should be reviewed. Data on drain flow must be looked at in conjunction with reservoir-level data. Correlating the reservoir level with the drain flow can help to determine if there is a problem. If a drain flow is observed that is atypical for the given reservoir level, more investigation is essential. During the field examination, inspectors should:

- Locate each toe drain outfall.
- Measure the flow. A simple method of measuring the flow from a toe drain outfall is to catch the flow from the pipe in a container of known volume and to time how long it takes to fill the container. The flow rate is usually recorded in gallons per minute.
- Compare the amount of flow with the amount of flow expected for the current reservoir level based on previous readings.

A drain that has no flow at all could indicate that there is no seepage in the area of the dam serviced by the drain, or that the drain is plugged or blocked. If the drain has never functioned, it could mean that the drain was designed or installed incorrectly. If the drain used to flow but has now stopped flowing, it may have become plugged. A plugged drain can be a genuine problem because seepage may begin to exit downslope, or may contribute to internal pressure and instability. If possible, blocked drains should be cleaned so

that the controlled release of seepage may be restored.

Decreasing amounts of flow from a drain for the same reservoir level may indicate that the drain is becoming blocked. Conversely, a sudden increase in drain flow may indicate that the core is becoming less watertight, possibly as the result of transverse cracking.

If relief wells have been installed at a dam, they may help to monitor seepage also. Before conducting a visual inspection of an embankment dam that has relief wells, inspectors should:

- Review the site plan to determine the location of the wells.
- Review previous data on both the reservoir level and well flow. Data on relief well flow must be evaluated in conjunction with reservoir-level data. Knowing how the reservoir level affects the relief well flow can help determine if there is a problem.
- If the flow from a relief well seems to be unusual for the given reservoir level, more investigation is essential.

During the visual inspection, the inspectors should:

- Locate each relief well.
- Visually check whether water flow is occurring.
- Compare the amount of relief well flow measured with the amount of flow anticipated for the current reservoir level based on previous readings.

If no water is flowing from the relief well, determine if a flow should be present based on the assessment of the previous readings and the current reservoir level. If water is flowing, measure the rate of flow. The rate of flow can be measured either at the well or at the collector pipe discharge. Weirs, flumes, or a bucket and stopwatch can be used to measure the flow rate.

If the relief well flow is less than the amount anticipated, the well screens or filters may have become clogged and might require

cleaning. If the flow is greater than the amount expected, there may be excessive seepage. Make sure that the flow rate and reservoir level are accurately recorded. Inspectors should also note that there has been a change from the well-flow trends previously observed.

In addition to measuring the flow rate of seepage, inspectors should evaluate the clarity of the seepage. Turbidity is cloudy seepage, which indicates that soil particles are suspended in the water. Turbidity indicates that the water passing through the embankment or foundation is carrying soil with it. Turbidity is cause for extreme concern. Each time seepage is measured or inspected, the clarity of the seepage should also be evaluated for change.

An effective way of detecting a change in turbidity is to collect several water samples as follows:

- (1) Collect a sample of the water in a quart jar. Date the jar and note the level of clarity. Store the jar in a safe location.
- (2) Repeat step 1 each time seepage flow is measured until several samples have been collected.
- (3) Each time a sample is collected, shake up each jar and visually compare the new sample with the samples collected previously. Look for changes in the cloudiness of the samples. Also, note the amount of sediment that accumulates in the bottom of the jars as suspended material settles out.

If the seepage water is clear, but it is suspected that it contains dissolved material from the foundation (because, for instance, seepage has increased without any signs of turbidity), it may be necessary to perform water quality testing.

The rate and turbidity of seepage flow should be recorded during each visual inspection. If seepage problems are suspected, then the frequency of inspections should be determined by a qualified dam safety professional. If seepage problems continue to occur, further testing should be conducted by a quali-


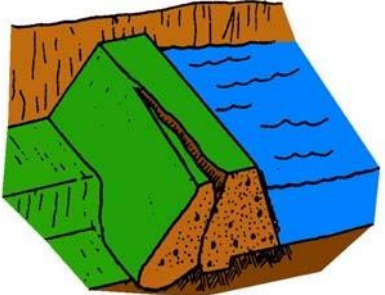
fied dam safety professional. Seepage problems are a grave concern, and uncontrolled seepage is one of the main causes of embankment dam failure.

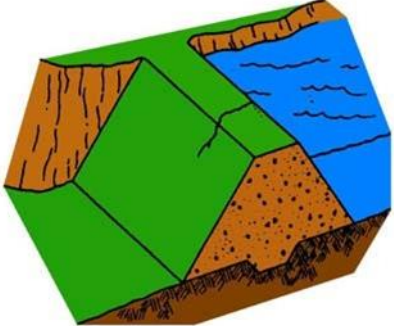
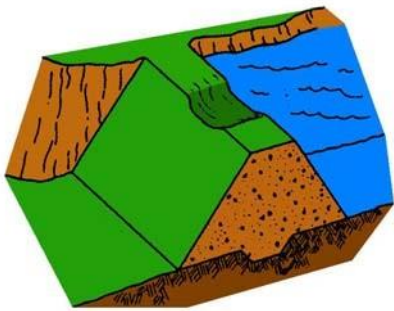
Piezometers or monitoring wells can be installed in the embankment to monitor the level of water in the soil. These wells can be useful for detecting changes in seepage within the embankment, and for detecting excessive seepage zones if they are installed at intervals along the entire length of the embankment. The level to which water will rise in a piezometer is equal to the pressure at that location. If there is no seepage present, there will be no water observed in the piezometer well. They can also be installed in the foundation and abutments to monitor groundwater. Installation of piezometers requires a qualified geotechnical contractor. Piezometer monitoring is not as effective as seepage monitoring because piezometers only measure conditions at the exact location at which they are installed.

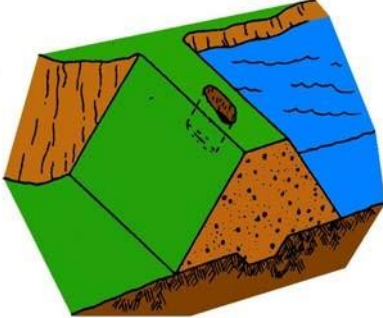

4.12 Embankment Dam Inspection Sketches

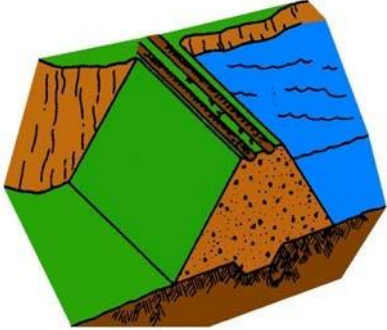
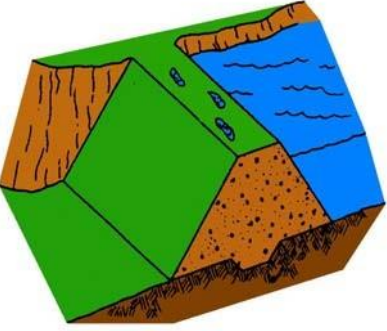
Sketches of conditions that may be found on a dam embankment during a visual inspection are presented in Table 4-1. While most of the conditions shown in the drawings can be corrected by routine and periodic maintenance carried out by the dam owner, some of the problems noted are of a nature that threatens the safety and integrity of the dam and need the attention of qualified engineers and geologists to decide on remedial measures. For example, a geotechnical engineer needs to be consulted if a slope stability or soil issue exists. Or, an engineer with hydrologic and hydraulic experience may be needed to calculate the needed spillway capacity. Depending on the severity of a condition, the dam owner may need to take immediate action to prevent the problem from worsening, including contacting repair contractors and notifying local disaster management authorities.

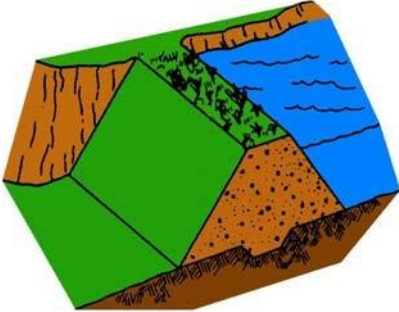
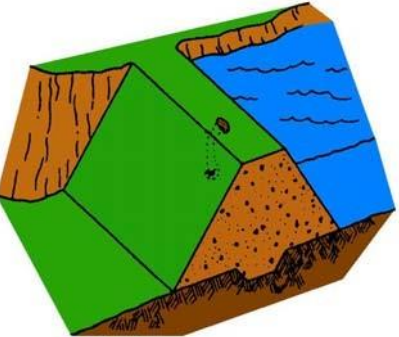
Table 4-1. Sketches of problems that are found at embankment dams, the hazards created, and remedial measures

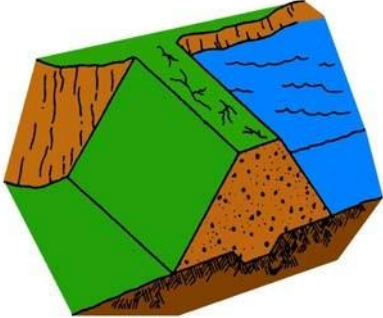
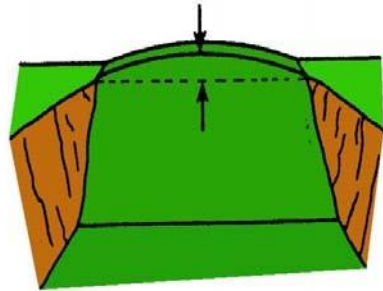
Problem	Probable causes	Hazards created	Remedial measures
 <p>Longitudinal Cracking</p>	<ol style="list-style-type: none"> <li>1. The uneven settlement between adjacent sections or zones within the embankment. <li>2. A foundation failure that is causing loss of support to the embankment. 	<ol style="list-style-type: none"> <li>1. A local area of low strength within embankment is created. This could be the point of initiation of future structural movement, deformation, or failure. <li>2. An entrance point is created for surface run-off into the embankment allowing saturation of adjacent embankment area and lubrication which could lead to localized failure. 	<ol style="list-style-type: none"> <li>1. Inspect crack and carefully record location, length, depth, width, alignment, and other pertinent physical features. Immediately stake out limits of cracking. Monitor frequently. <li>2. An engineer should decide on the cause of cracking and supervise steps necessary to reduce the danger to the dam and to correct the condition. <li>3. Effectively seal the cracks at the crest's surface to prevent infiltration by surface water. <li>4. Continue to monitor crest for evidence of further cracking routinely
 <p>Vertical Displacement</p>	<ol style="list-style-type: none"> <li>1. Vertical movement between adjacent sections of the embankment. <li>2. Structural deformation or failure caused by structural stress or instability, or by the failure of the foundation. 	<ol style="list-style-type: none"> <li>1. Creates a local area of low strength within embankment which could cause future movement. <li>2. Leads to structural instability or failure. <li>3. Creates an entry point for surface water that could further lubricate failure plane. <li>4. Reduces available embankment cross section. 	<ol style="list-style-type: none"> <li>1. Carefully inspect displacement and record its location, vertical and horizontal displacement, length, and other physical features. Immediately stake out limits of cracking. <li>2. An engineer should figure out the cause of the displacement and supervise all steps necessary to reduce the danger to the dam and correct the condition. <li>3. Excavate area to the bottom of the vertical movement. Backfill excavation, using competent material and proper construction techniques under the supervision of an engineer. <li>4. Continue to monitor areas routinely for evidence of future cracking or movement.

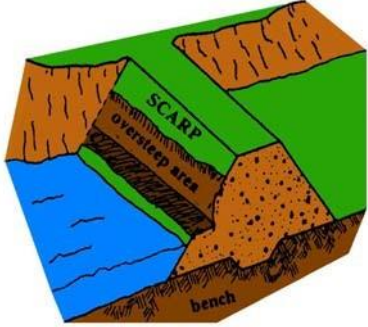
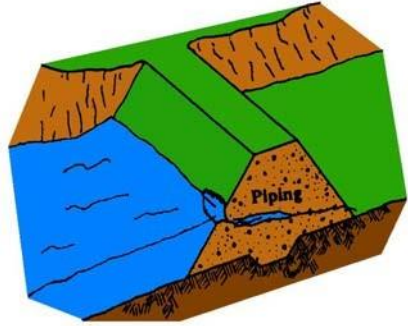
Problem	Probable causes	Hazards created	Remedial measures
 <p>Transverse Cracking</p>	<ol style="list-style-type: none"> 1. Uneven movement between adjacent segments of the embankment. 2. Deformation caused by structural stress or instability. 	<ol style="list-style-type: none"> 1. Can create a path for seepage through the embankment cross section. 2. Creates a local area of low strength within embankment. Future structural movement, deformation, or failure could begin at this point. 3. Makes an entrance point for surface run-off to enter embankment. 	<ol style="list-style-type: none"> 1. Inspect crack and carefully record crack location, length, depth, width, and other pertinent physical features. Stake out limits of cracking. 2. An engineer should figure out the cause of cracking and supervise all steps necessary to reduce the danger to the dam and to correct the condition. 3. Excavate crest along the crack to a point below its bottom. Then backfill excavation using competent material and proper construction techniques. This will seal the crack against seepage and surface run-off. 4. Continue to check the crest routinely for evidence of future cracking.
 <p>Low Area on Crest of Dam</p>	<ol style="list-style-type: none"> 1. Movement between adjacent portions of the structure. 2. Uneven deflection of dam under loading by the reservoir. 3. Structural deformation or failure near the area of misalignment. 4. Excessive settlement in the embankment or foundation directly beneath the low area in the crest. 5. Internal erosion of embankment material. 6. The foundation is spreading in the upstream and/or downstream direction. 7. Prolonged wind erosion of crest area. 8. Improper final grading following construction. 	<ol style="list-style-type: none"> 1. Area of misalignment is usually accompanied by low area in crest which reduces freeboard. 2. Can produce local areas of low embankment strength which may lead to failure. 3. Reduces freeboard available to pass flood flows safely through the spillway 	<ol style="list-style-type: none"> 1. Set up monuments along the length of the dam crest to determine exact amount, location, and extent of settlement in the crest. 2. An engineer should figure out the cause of low area and supervise all steps necessary to reduce the threat to the dam and to correct the condition. 3. Re-establish uniform crest elevation over crest length by placing fill in the low area using proper construction techniques. This should be supervised by an engineer. 4. Re-establish monuments across the crest of dam and monitor monuments on a routine basis to detect probable future settlement.

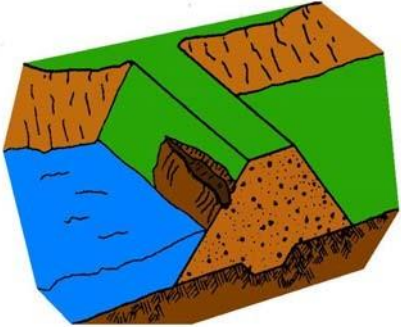
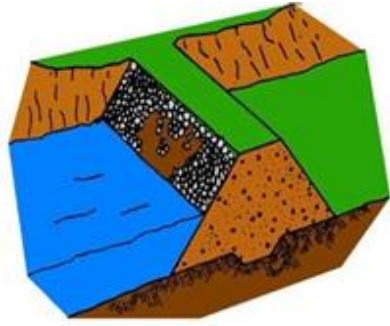
Problem	Probable causes	Hazards created	Remedial measures
 <p style="text-align: center;">Sinkhole on Crest</p>	<ol style="list-style-type: none"> 1. Rodent activity. 2. Hole in outlet conduit is causing erosion of embankment material. 3. Internal erosion or piping of embankment material by seepage. 4. Breakdown of dispersive clays within embankment by seepage waters. 	<ol style="list-style-type: none"> 1. Void spaces within the dam could cause localized caving, sloughing, instability, or reduced embankment cross section. 2. Entrance point for surface water. 	<ol style="list-style-type: none"> 1. Carefully inspect and record location and physical characteristics (depth, width, length) of the sinkhole. 2. An engineer should figure out the cause of the sinkhole and supervise all steps necessary to reduce the threat to the dam and to correct the condition. 3. Excavate sinkhole, slope sides of the excavation, and backfill hole with competent material using proper construction techniques. This should be supervised by an engineer.
 <p style="text-align: center;">Gully Originating at Crest</p>	<ol style="list-style-type: none"> 1. Poor grading and improper drainage of the embankment crest. Improper drainage causes surface run-off to collect and drain off crest at a low point in the upstream or downstream shoulder. 2. Inadequate spillway capacity which has resulting in overtopping of the dam and erosion of the downstream embankment slope. 	<ol style="list-style-type: none"> 1. Can reduce available freeboard. 2. Reduces cross-sectional area of the dam. 3. Inhibits access to all parts of the crest and dam. 	<ol style="list-style-type: none"> 1. Restore freeboard to the dam by adding fill material in the low area, using proper construction techniques. 2. Re-grade crest to allow proper drainage of surface run-off. 3. If gully was caused by over-topping, install a properly sized spillway that satisfies current design standards. This should be done by an engineer. 4. Re-establish protective cover on the embankment.

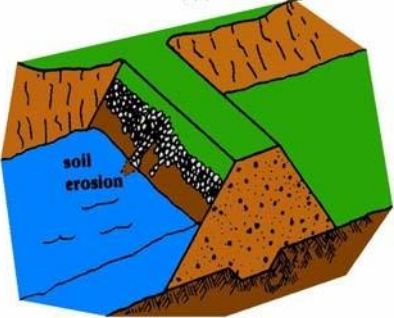
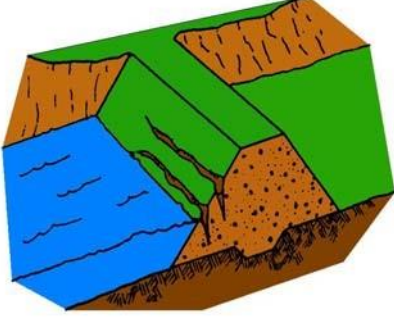
Problem	Probable causes	Hazards created	Remedial measures
 <p>Ruts along Crest</p>	<ol style="list-style-type: none"> 1. Heavy vehicular traffic without adequate or proper maintenance or proper crest surfacing. 2. Animal trails, particularly those made by cattle. 	<ol style="list-style-type: none"> 1. Inhibits easy access to all parts of the dam crest. 2. Allows continued development of rutting. 3. Allows standing water to collect and saturate crest of the dam. 4. Operating and maintenance vehicles can become stuck. 	<ol style="list-style-type: none"> 1. Drain standing water from the ruts. 2. Re-grade and re-compact the embankment crest to restore integrity and provide proper drainage toward the upstream slope. 3. Provide gravel or road base material to accommodate traffic. 4. Perform periodic maintenance and re-grading to prevent reformation of ruts.
 <p>Puddling on Crest; Poor Drainage</p>	<ol style="list-style-type: none"> 1. Poor grading and improper drainage of the embankment crest. 2. Localized consolidation or settlement on crest allows puddles to develop. 	<ol style="list-style-type: none"> 1. Causes localized saturation of the dam crest. 2. Inhibits access to all portions of the dam and the crest. 3. Becomes progressively worse if not corrected. 	<ol style="list-style-type: none"> 1. Drain standing water from puddles. 2. Re-grade and re-compact crest to restore integrity and allow proper drainage toward the upstream slope. 3. Install gravel or road base material to accommodate traffic. 4. Perform periodic maintenance and re-grading to prevent reformation of ruts.

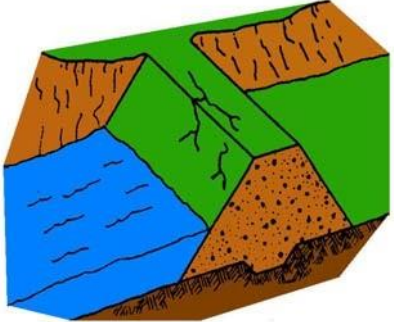
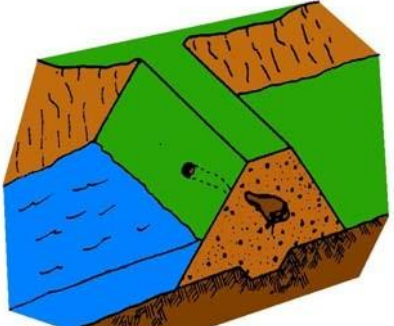
Problem	Probable causes	Hazards created	Remedial measures
 <p>Obscuring Vegetation</p>	<ol style="list-style-type: none"> 1. Neglect of dam and lack of proper maintenance procedures. 	<ol style="list-style-type: none"> 1. Obscures vast areas of the dam preventing adequate, accurate visual inspection of all parts of the dam. Problems that threaten the integrity of the dam can develop and go undetected until they progress to a point where the dam's safety is threatened. 2. Associated root systems grow and penetrate the dam's cross section. When the vegetation dies, the decaying root systems form paths for seepage. This reduces the effective seepage path through the embankment and could lead to piping situations. 3. Prevents easy access to all portions of the dam for operation, maintenance, and inspection. 4. Creates an attractive habitat for rodents. 	<ol style="list-style-type: none"> 1. Remove all excessive growth from the dam including trees, bushes, brush, and growth other than grass. Grass should be encouraged on all segments of the dam to prevent erosion by surface run-off. Root systems should also be removed if possible. The void that results from removing the root system should be backfilled with competent, well-compacted soil. 2. Future undesirable growth should be removed by cutting or spraying, as part of an annual maintenance program. 3. All cuttings or debris resulting from the vegetation removal should be properly disposed of outside the reservoir basin at once.
 <p>Rodent Activity on Crest</p>	<ol style="list-style-type: none"> 1. Burrowing animals. 	<ol style="list-style-type: none"> 1. Entrance point for surface runoff to enter dam. Could saturate adjacent portions of the dam. 2. Especially dangerous if rodent burrows penetrate an embankment below the phreatic line. During periods of high reservoir levels, the seepage path through the dam would be reduced, and a piping problem could develop. 	<ol style="list-style-type: none"> 1. Completely backfill the hole with competent, well-compacted material. 2. Initiate a rodent control program to prevent the propagation of the burrowing animal population and to avoid future damage to the dam.

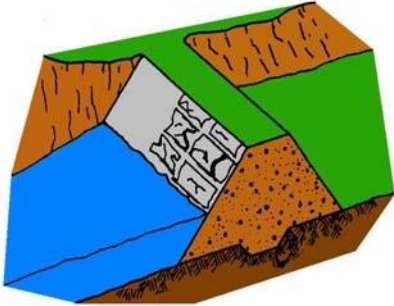
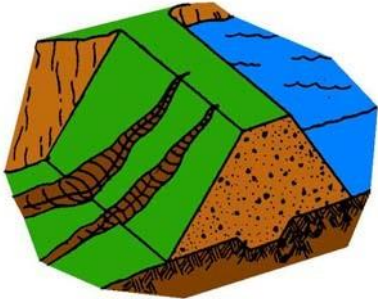
Problem	Probable causes	Hazards created	Remedial measures
 <p>Desiccation Cracks</p>	<ol style="list-style-type: none"> 1. The material on the crest of dam expands and contracts with alternate wetting and drying of weather cycles. 2. Drying cracks are usually short, shallow, narrow, and large in number. 	<ol style="list-style-type: none"> 1. Creates an entrance point for surface run-off and surface moisture, causing saturation of adjacent embankment areas. 2. The saturation and subsequent drying of the dam could cause further cracking. 	<ol style="list-style-type: none"> 1. The material on the crest of dam expands and contracts with alternate wetting and drying of weather cycles. Drying cracks are usually short, shallow, narrow, and large in number. 2. Seal surface of cracks with a tight, impervious material. 3. Routinely grade crest to enable proper drainage and fill in cracks. 4. Cover crest with non-plastic (not clay) material to prevent significant moisture content variations with respect to time. 5. Draw the reservoir down if the safety of the dam is threatened.
 <p>Crest Camber</p>	<ol style="list-style-type: none"> 1. The results of construction. Proportionally more fill is placed on the crest in higher segments of the embankment during construction to compensate for expected settlement within the dam and foundation. 	<ol style="list-style-type: none"> 1. None. 	<ol style="list-style-type: none"> 1. None.

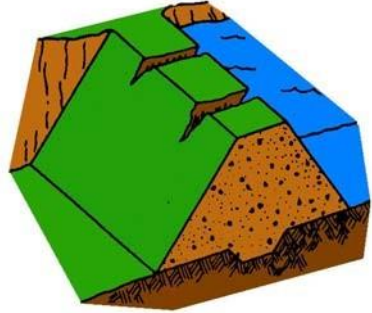
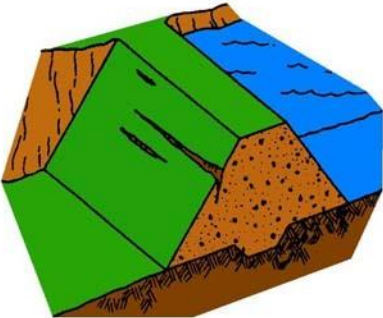
Problem	Probable causes	Hazards created	Remedial measures
 <p>Scarps, Benches, Overly Steep Areas</p>	<ol style="list-style-type: none"> 1. Wave action, local settlement, or ice action cause soil and rock to erode and slide to the lower part of the slope forming a bench. 	<ol style="list-style-type: none"> 1. The eroded area lessens the width and height of the embankment and could lead to increased seepage or the overtopping of the dam by flood flows. 	<ol style="list-style-type: none"> 1. Figure out the exact cause of the scarps. 2. Carry out necessary earthwork, restore embankment to the designed slope, install adequate protection (bedding and riprap).
 <p>Sinkhole on Embankment Slope</p>	<ol style="list-style-type: none"> 1. The piping of embankment material or foundation material causes a sinkhole. 2. The cave-in of an eroded cavern can result in a sink hole. 3. A small hole in the wall of an outlet pipe can develop a sink hole. 	<ol style="list-style-type: none"> 1. This condition can empty a reservoir through a small hole in the wall of an outlet pipe. 2. Rapid outflow through the sinkhole can lead to failure of a dam as soil pipes through the foundation or a permeable part of the dam 	<ol style="list-style-type: none"> 1. Inspect other areas of the dam for seepage or more sinkholes. 2. Find the exact cause of sinkholes. 3. Check seepage and leakage outflows for dirty water. 4. A qualified engineer should inspect the conditions and recommend further actions to be taken.


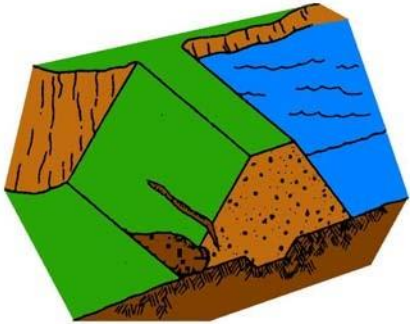
Problem	Probable causes	Hazards created	Remedial measures
 <p>Embankment Slide, Slump, or Slip</p>	<ol style="list-style-type: none"> 1. Earth or rocks move down the slope along a slippage surface because they were on too steep a slope 2. The foundation moves and a slide occurs. 	<ol style="list-style-type: none"> 1. A series of slides can lead to obstruction of the outlet or failure of the dam. 2. Shallow slides on the downstream slope also be a sign of an overly steep slope or poorly compacted soils or a loss of strength in the embankment material. 3. Deep-seated slides are serious threats to the safety of the dam and may be recognized by the presence of a well-defined scarp or bulging on the slope or at the toe. 4. Arc-shaped cracks on the slope are usually indications that a slide is beginning. This type of crack may develop into a large scarp at the top of the slide. 	<ol style="list-style-type: none"> 1. Evaluate the extent of the slide. Monitor slide. Draw the reservoir level down if the safety of the dam is threatened. 2. A qualified engineer should inspect the conditions and recommend further actions to be taken.
 <p>Dislodged Riprap</p>	<ol style="list-style-type: none"> 1. Inferior quality riprap has deteriorated because of freeze-thaw action and/or vandalism. 2. Wave action or ice action has displaced the riprap. Round and similar sized rocks have rolled downhill. 	<ol style="list-style-type: none"> 1. Wave action against these unprotected areas erodes the embankment thereby decreasing its width. 2. Damage near the crest is more severe because the embankment could be breached easier as a result. 	<ol style="list-style-type: none"> 1. Re-establish the original slope. Place bedding and competent riprap. 2. Include proper filters below the protective riprap, either stone of the right size and gradation or a geotextile.

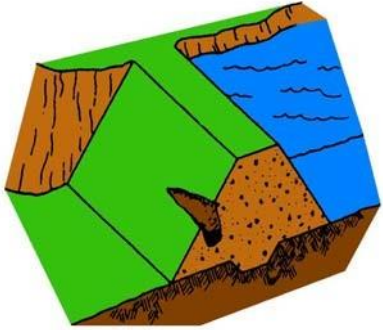
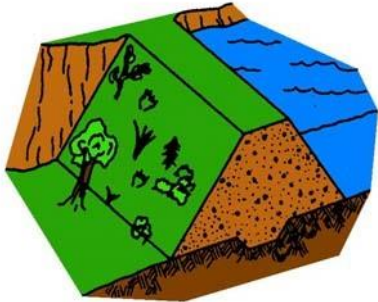
Problem	Probable causes	Hazards created	Remedial measures
 <p>Erosion of Soil Beneath Riprap</p>	<ol style="list-style-type: none"> 1. Similar-sized rocks allow waves to pass between them and erode small gravel particles and soil. 	<ol style="list-style-type: none"> 1. The soil is eroded away from behind the riprap. This allows the riprap to settle, offering less protection and decreased embankment width. 	<ol style="list-style-type: none"> 1. Re-establish effective slope protection. Place bedding material. A qualified engineer needs to calculate the gradation and size of rock required for bedding and riprap. 2. A qualified engineer should inspect the conditions and recommend further actions to be taken.
 <p>Large Horizontal Cracks on Slope</p>	<ol style="list-style-type: none"> 1. A part of the embankment has moved because of a loss of strength, or the foundation may have moved, causing embankment movement. 	<ol style="list-style-type: none"> 1. Can promote internal erosion of the dam which might lead to a breach from piping. 	<ol style="list-style-type: none"> 1. Depending on the amount of embankment involved, draw reservoir level down. 2. A qualified engineer should inspect the conditions and recommend further actions to be taken.

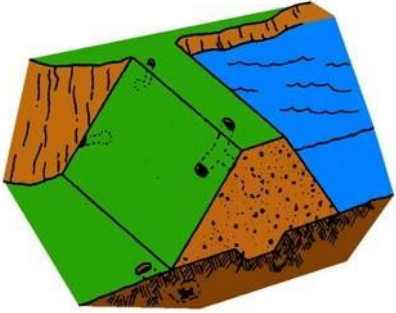

Problem	Probable causes	Hazards created	Remedial measures
 <p>Desiccation Cracks on Slope</p>	<ol style="list-style-type: none"> <li>1. The soil loses its moisture and shrinks, causing cracks. <li>2. Usually seen on the embankment crest and downstream slope mostly. 	<ol style="list-style-type: none"> <li>1. Heavy rains can fill up cracks and cause small portions of the embankment to move along internal slip surface. 	<ol style="list-style-type: none"> <li>1. Monitor cracks for increases in width, depth, or length. <li>2. A qualified engineer should inspect the condition and recommend further actions to be taken.
 <p>Animal Burrows on Slope</p>	<ol style="list-style-type: none"> <li>1. Holes, tunnels, and caverns are caused by animal burrows. <li>2. Certain habitats like cattail-type plants and trees close to the reservoir encourage these animals. 	<ol style="list-style-type: none"> <li>1. If a tunnel exists through most of the dam, it can lead to failure of the dam 	<ol style="list-style-type: none"> <li>1. Remove rodents. <li>2. Determine the exact location of digging and extent of tunneling. <li>3. Remove habitat. <li>4. Repair damages.

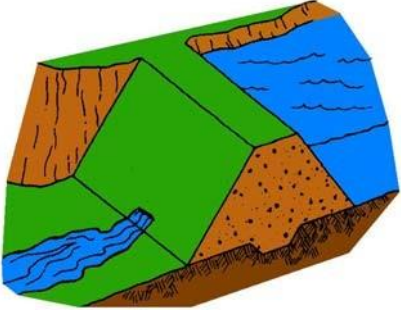
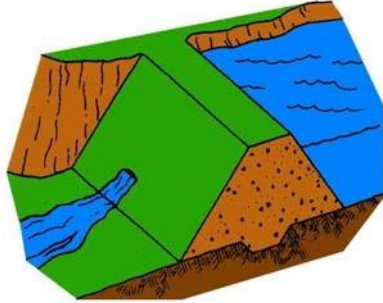
<p>Problem</p>	<p>Probable causes</p>	<p>Hazards created</p>	<p>Remedial measures</p>
 <p>Cracked or Deteriorated Concrete Face</p>	<p>1. Concrete deteriorated because of weathering. Joint filler deteriorated or displaced</p>	<p>1. The soil is eroded behind the face and caverns can be formed. Unsupported sections of concrete crack. Ice action may displace concrete.</p>	<p>1. Determine cause. Either patch with grout or contact engineer for permanent repair method. 2. If damage is extensive, a qualified engineer should inspect the conditions and recommend further actions to be taken</p>
 <p>General Erosion on Slope</p>	<p>1. Water from intense rainstorms or snowmelt carries surface material down the slope, resulting in continuous troughs.</p>	<p>1. Water from intense rainstorms or snowmelt carries surface material down the slope, resulting in continuous troughs.</p>	<p>1. The preferred method to protect eroded areas is rock or riprap. 2. Re-establishing protective grasses can be adequate if the problem is detected early.</p>

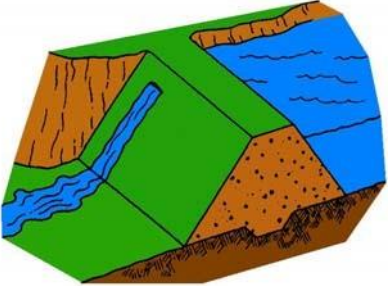
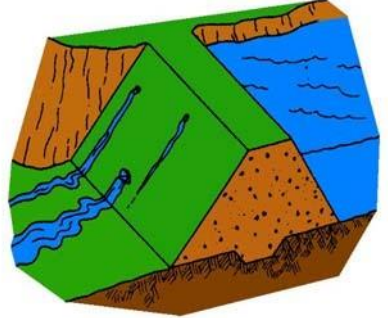
Problem	Probable causes	Hazards created	Remedial measures
 <p>The diagram shows a cross-section of a dam embankment with a reservoir on top. A vertical crack runs across the width of the embankment, from the surface down into the soil layers. The embankment is shown in green on top and brown below, with a blue reservoir on the right.</p> <p>Transverse Cracking on Slope</p>	<ol style="list-style-type: none"> 1. Drying and shrinkage of surface material are the most common causes. 2. Differential settlement of the embankment also leads to transverse cracking (e.g., center settles more than abutments). 	<ol style="list-style-type: none"> 1. Shrinkage cracks allow water to enter the embankment. This promotes saturation and increases freeze-thaw action. 2. Settlement cracks can lead to seepage of reservoir water through the dam. 3. Can give rise to an uncontrolled release of water through a breach. 	<ol style="list-style-type: none"> 1. If necessary plug upstream end of the crack to prevent flows from the reservoir. 2. A qualified engineer should inspect the conditions and recommend further actions to be taken.
 <p>The diagram shows a cross-section of a dam embankment with a reservoir on top. A diagonal crack runs parallel to the slope of the embankment, from the surface down into the soil layers. The embankment is shown in green on top and brown below, with a blue reservoir on the right.</p> <p>Longitudinal Cracking on Slope</p>	<ol style="list-style-type: none"> 1. Drying and shrinkage of surface material. 2. Downstream movement or settlement of embankment. 	<ol style="list-style-type: none"> 1. Can be an early warning of a potential slide. 2. Shrinkage cracks allow water to enter the embankment and freezing will further crack the embankment. 3. Settlement or slide indicating loss of strength in embankment can lead to failure. 	<ol style="list-style-type: none"> 1. If cracks are from drying, dress area with well-compacted material to keep surface water out and natural moisture in. 2. If cracks are extensive, a qualified engineer should inspect the conditions and recommend further actions to be taken.

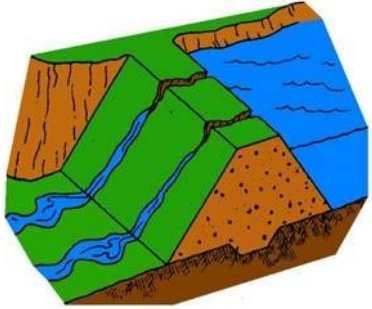
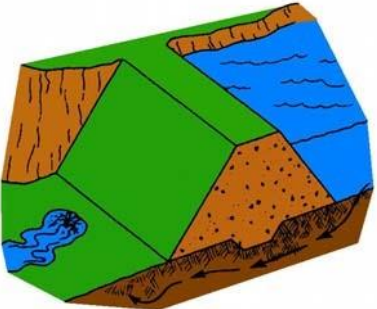
Problem	Probable causes	Hazards created	Remedial measures
 <p>Slide/Slough on Slope</p>	<ol style="list-style-type: none"> <li>1. Lack of or loss of strength of embankment material. <li>2. Loss of strength can be attributed to infiltration of water into the embankment or loss of support by the foundation. 	<ol style="list-style-type: none"> <li>1. Can lead to failure of the dam. 	<ol style="list-style-type: none"> <li>1. Measure the extent and displacement of the slide. <li>2. If continued movement is seen, begin lowering water level until movement stops. <li>3. Have a qualified engineer inspect the condition and recommend further action.
 <p>Slump (Limited in Extent)</p>	<ol style="list-style-type: none"> <li>1. Preceded by erosion undercutting a part of the slope. <li>2. Can also be found on relatively steep slopes. 	<ol style="list-style-type: none"> <li>1. Can expose impervious zone to erosion. 	<ol style="list-style-type: none"> <li>1. Inspect area for seepage. <li>2. Monitor for progressive failure. <li>3. Have a qualified engineer inspect the condition and recommend further action.

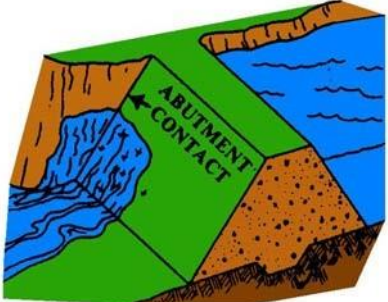
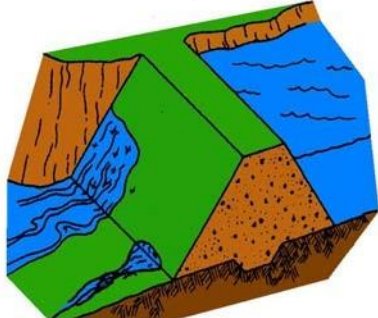
Problem	Probable causes	Hazards created	Remedial measures
 <p>Sinkhole Collapse on Slope</p>	<ol style="list-style-type: none"> 1. Lack of adequate compaction; rodent hole below; piping through embankment or foundation. 	<ol style="list-style-type: none"> 1. Shortens seepage path, can lead to washout of the embankment and an uncontrolled release of impounded water. 	<ol style="list-style-type: none"> 1. Inspect for and immediately repair rodent holes. Control rodents to prevent future damage. 2. Have a qualified engineer inspect the condition and recommend further action.
 <p>Obscuring Trees and Brush on Slope</p>	<ol style="list-style-type: none"> 1. Natural vegetation other than short grass on the embankment slope and along the embankment toe. 	<ol style="list-style-type: none"> 1. Large tree roots can create seepage paths. 2. The brush can obscure visual inspection and harbor rodents. 	<ol style="list-style-type: none"> 1. Remove all large, deep-rooted trees and shrubs on or near the embankment. Properly backfill void. 2. Control all other vegetation on the embankment that obscures visual inspection.

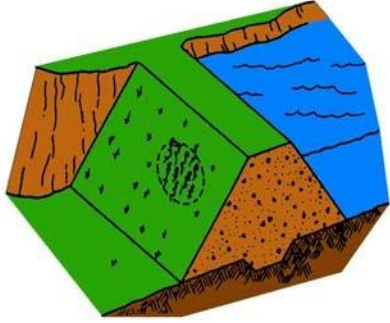
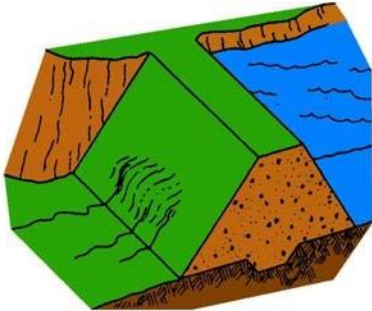
Problem	Probable causes	Hazards created	Remedial measures
 <p>Rodent Activity on Slope</p>	<p>1. Overabundance of rodents. Probably because of excessive vegetation on embankment slope and along embankment toe.</p>	<p>1. If rodent holes intersect with phreatic surface, the length of the seepage path will be reduced leading to increased flow and possible piping failures.</p>	<p>1. Eliminate rodents to prevent additional damage to embankment. 2. Backfill existing rodent holes. 3. Remove excessive vegetation that provides attractive habitat for rodents. Maintain a short layer of grass on embankment that is cut often.</p>
 <p>Ruts from Livestock/Cattle Traffic on Slope</p>	<p>1. Excessive travel by livestock; especially harmful to slope when wet.</p>	<p>1. Creates areas bare of erosion protection and causes erosion channels. Allows water to stand. Area susceptible to drying cracks</p>	<p>1. Fence livestock outside embankment area. 2. Repair eroded livestock trails with compacted soils and then revegetate. 3. Repair erosion protection, i.e., riprap, grass.</p>

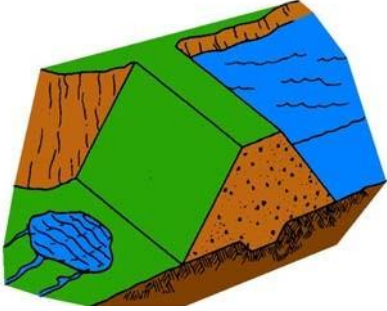
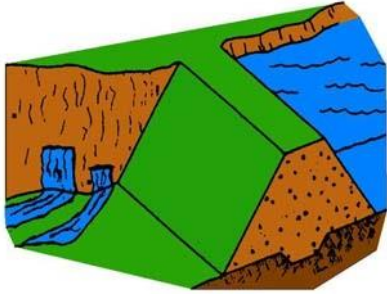
Problem	Probable causes	Hazards created	Remedial measures
 <p>Clear Water Flowing from a Point Source near Toe of Slope</p>	<ol style="list-style-type: none"> 1. Water has created an open pathway or pipe through the dam. 	<ol style="list-style-type: none"> 1. Continued flows can further erode embankment materials. This can lead to failure of the dam. 	<ol style="list-style-type: none"> 1. Begin measuring outflow quantity. 2. If the amount of discharge is increasing, the water level in the reservoir should be lowered until the flow stabilizes or stops. 3. A qualified engineer should inspect the condition and recommend further actions to be taken.
 <p>Muddy Water Flowing from a Point Source near Toe of Slope</p>	<ol style="list-style-type: none"> 1. Water has created an open pathway, channel, or pipe through the dam. The water is eroding and carrying embankment material. 2. Significant amounts of water have accumulated in the downstream slope. Water and embankment materials are exiting at one point. Surface agitation may be causing the muddy water. 	<ol style="list-style-type: none"> 1. Continued flows can further erode embankment materials. This can lead to failure of the dam. 	<ol style="list-style-type: none"> 1. Begin measuring outflow quantity and proving whether water is getting muddier, staying the same, or clearing up. 2. If the discharge is increasing, the water level in the reservoir should be lowered until the flow stabilizes or stops. 3. A qualified engineer should inspect the condition and recommend further actions to be taken.

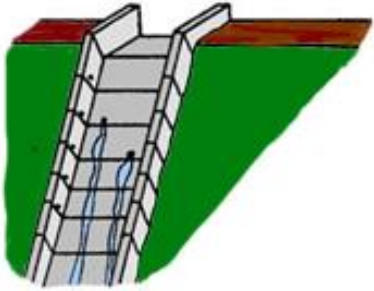
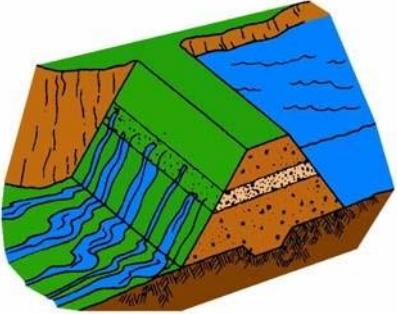
Problem	Probable causes	Hazards created	Remedial measures
 <p>Water Flowing from a Point Source High on Slope</p>	<ol style="list-style-type: none"> 1. Rodents, frost action or poor construction have allowed water to create an open pathway or pipe through the embankment. 	<ol style="list-style-type: none"> 1. Continued flows can saturate portions of the embankment and lead to slides in the area. 2. Continued flows can further erode embankment materials and result in failure of the dam. 	<ol style="list-style-type: none"> 1. Begin measuring outflow quantity. 2. If the discharge is increasing, the water level in the reservoir needs to be lowered until the leak stops. 3. Search for opening on the upstream side and plug it if possible. 4. A qualified engineer should inspect the condition at once and recommend further action to be taken.
 <p>Water Flowing from Rodent Holes or Animal Burrows</p>	<ol style="list-style-type: none"> 1. Diggings by the rodent have shortened the flow path. 	<ol style="list-style-type: none"> 1. Continued flows can further erode embankment material and lead to failure of the dam. 	<ol style="list-style-type: none"> 1. Locate any entrance points on the upstream slope and plug them. 2. If the quantity of flow is increasing, the water level in the reservoir needs to be lowered until the leak stops. 3. Bring a halt to the rodent activity. 4. A qualified engineer should inspect the condition and recommend further actions to be taken.

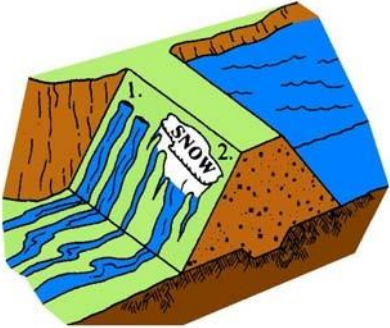
Problem	Probable causes	Hazards created	Remedial measures
 <p>Stream of Water Flowing from Cracks near Crest</p>	<ol style="list-style-type: none"> 1. Severe drying has caused shrinkage of embankment material. 2. Settlement in the embankment or foundation is causing the transverse cracks. 	<ol style="list-style-type: none"> 1. Flow through the crack can cause failure of the dam. 	<ol style="list-style-type: none"> 1. Plug the upstream side of the crack to stop the flow. 2. The water level in the reservoir should be lowered until it is below the elevation of the cracks. 3. A qualified engineer should inspect the condition and recommend further actions to be taken.
 <p>Seepage Water Flowing from a Boil in the Foundation</p>	<ol style="list-style-type: none"> 1. Some part of the foundation material is providing a flow path. This could be caused by a layer of sand or gravel in the foundation. 	<ol style="list-style-type: none"> 1. Increased flows can lead to erosion of the foundation and failure of the dam. 	<ol style="list-style-type: none"> 1. Examine the boil for transportation of foundation materials. 2. If soil particles are moving downstream, sandbags or earth should be used to create a dike around the boil. The pressure created by the water level within the dike may control flow velocities and temporarily prevent further erosion. A graded filter may also be placed in the boil to inhibit soil loss. 3. If erosion is becoming greater, the reservoir level should be lowered. 4. A qualified engineer should inspect the condition and recommend further actions to be taken.

Problem	Probable causes	Hazards created	Remedial measures
 <p style="text-align: center;">Seepage Flowing from an Abutment Contact</p>	<ol style="list-style-type: none"> 1. Water is flowing through pathways in the abutment. 2. Water is flowing through the embankment. 	<ol style="list-style-type: none"> 1. Can lead to erosion of embankment materials and failure of the dam. 	<ol style="list-style-type: none"> 1. Investigate leakage area to determine the quantity of flow and extent of saturation. 2. Inspect daily for developing slides. 3. The water level in the reservoir may need to be lowered to assure the safety of the embankment. 4. A qualified engineer should inspect the conditions and recommend further actions to be taken.
 <p style="text-align: center;">Large Wet Area with Discharge on Slope above Toe</p>	<ol style="list-style-type: none"> 1. A seepage path has developed through the abutment or embankment. 	<ol style="list-style-type: none"> 1. Increased flows could lead to erosion of embankment material and failure of the dam. 2. Saturation of the embankment may result in local slides which could cause failure of the dam. 	<ol style="list-style-type: none"> 1. Stake out the saturated area and monitor for growth or shrinking. 2. Measure any outflows as accurately as possible. 3. Reservoir level may need to be lowered if saturated areas increase in size at a fixed storage level or if flow increases. 4. A qualified engineer should inspect the condition and recommend further actions to be taken.

Problem	Probable causes	Hazards created	Remedial measures
 <p>Marked Change in Vegetation on Slope</p>	<ol style="list-style-type: none"> 1. Runoff is being concentrated in shallow depressions which enable vegetation other than grass to thrive. 2. Natural seeding by the wind. 3. Change in seed type during initial post construction seeding. 	<ol style="list-style-type: none"> 1. Can be a sign of a saturated area. 	<ol style="list-style-type: none"> 1. Use probe or shovel to decide if the ground in this area is wetter than in surrounding areas. 2. If the area shows wetness when surrounding areas do not, a qualified engineer should inspect the condition and recommend further actions to be taken.
 <p>Bulge in Large Wet Area on Slope</p>	<ol style="list-style-type: none"> 1. Downstream embankment materials have begun to move. 	<ol style="list-style-type: none"> 1. Failure of the embankment because of a large slide can follow these initial movements. 	<ol style="list-style-type: none"> 1. Compare embankment cross-section to the end of construction condition. 2. Stake out affected area and accurately measure outflow. 3. A qualified engineer should inspect the condition and recommend further actions to be taken

Problem	Probable causes	Hazards created	Remedial measures
 <p>The diagram shows a cross-section of a dam with a reservoir on the right. A large, irregularly shaped area of saturated soil is shown on the left side of the dam, representing a soggy area. The water table is high, and the soil is depicted as a brown, textured mass.</p> <p>Trampoline Effect in Large Soggy Area</p>	<ol style="list-style-type: none"> 1. Water moving rapidly through the embankment or foundation is being controlled or contained by a well-established turf root system. 	<ol style="list-style-type: none"> 1. The condition indicates excessive seepage in the area. If control layer of turf is destroyed, rapid erosion of foundation materials could result in failure of the dam. 	<ol style="list-style-type: none"> 1. Carefully inspect the area for out-flow quantity and any transported materials. 2. A qualified engineer should inspect the condition and recommend further actions to be taken.
 <p>The diagram shows a cross-section of a dam with a reservoir on the right. Water is shown flowing through cracks and fissures in the abutment materials on the left side of the dam. The water is depicted as blue lines flowing through the brown, textured abutment material.</p> <p>Leakage from Abutments Downstream from Dam</p>	<ol style="list-style-type: none"> 1. Water is flowing through cracks and fissures in the abutment materials. 	<ol style="list-style-type: none"> 1. Can lead to rapid erosion of abutment and evacuation of the reservoir. 2. Can result in massive slides near or downstream from the dam. 	<ol style="list-style-type: none"> 1. Carefully inspect the area to determine the quantity of flow and the amount of transported material. 2. A qualified engineer or geologist should inspect the condition and recommend further actions to be taken.

Problem	Probable causes	Hazards created	Remedial measures
 <p>Excessive Leakage from Spillway Underdrains</p>	<ol style="list-style-type: none"> 1. Drain or cutoff may have failed. 	<ol style="list-style-type: none"> 1. Excessive flows under the spillway could lead to erosion of foundation material and collapse of portions of the spillway. 2. Uncontrolled flows could result in loss of stored water. 	<ol style="list-style-type: none"> 1. Immediately measure flow quantity and check flows for transported drain material. 2. If flows are accelerating at a fixed storage level, the reservoir level should be lowered until the flow stabilizes or stops. 3. A qualified engineer should inspect the condition and recommend further actions to be taken.
 <p>Wet Area in a Horizontal Band</p>	<ol style="list-style-type: none"> 1. Frost layer or layer of sandy material in original construction. 	<ol style="list-style-type: none"> 1. Wetting of areas below the area of excessive seepage can lead to localized instability of the embankment. 2. Excessive flows can lead to accelerated erosion of embankment materials and failure of the dam. 	<ol style="list-style-type: none"> 1. Determine as closely as possible the amount of flow being produced. 2. If flow increases, reservoir level should be reduced until flow stabilizes or stops. 3. Stake out the exact area involved. 4. Using hand tools, try to identify the material allowing the flow. 5. A qualified engineer should inspect the condition and recommend further actions to be taken.

Problem	Probable causes	Hazards created	Remedial measures
 <p>Large Area on Slope Saturated from Above</p>	<ol style="list-style-type: none"> 1. Water is flowing through the embankment. 2. Snowdrifts are melting slowly during mild spring temperatures. 	<ol style="list-style-type: none"> 1. Can lead to saturation of embankment materials and local or massive slides which could cause failure of the dam. 	<ol style="list-style-type: none"> 1. Investigate saturated area to determine depth and extent of saturation. 2. Inspect daily for developing slides. 3. The water level in the reservoir may need to be lowered to assure the safety of the embankment. 4. A qualified engineer should inspect the conditions and recommend further actions to be taken.

Chapter 5. INSPECTING CONCRETE AND MASONRY DAMS

Systematic procedures are needed to inspect concrete and masonry dams to ensure that all features and areas are examined and to reduce the amount of time that is necessary. Concrete and masonry dams are usually stable when designed and constructed properly, and are not prone to overtopping failures, erosion, slides, burrowing animals, and piping, all of which are common safety problems at embankment dams. However, these types of dams require special visual inspection techniques because of their steep faces. Special safety harnesses, boatswain chairs, boats, video equipment, and scuba divers may be needed to complete the inspections.

5.1 Types of Concrete and Masonry Dams

Concrete and masonry dams include gravity, arch, roller-compacted, and buttress types. Gravity dams depend on their mass for stability and are well-suited to sites where there is a sound rock foundation, or occasionally a solid alluvial foundation. Arch dams are best suited to sites where the ratio of width between abutments to the height of the dam is not large and where the foundation at the abutments is solid rock capable of resisting arch thrust. Buttress dams rely on a sloping membrane, usually made of concrete, to transfer hydrostatic forces to a series of structural buttresses placed at right angles to the axis of the dam. The most common buttress dams are the flat-slab and multiple arch types. Buttress dams are best suited to wide valleys with gradually sloping abutments; they can be founded on rock or sound alluvium. Roller compacted concrete (RCC) dams are constructed with zero-slump concrete using vibratory rollers and continuous-placement methods.

Masonry dams are built mainly of stone, brick, rock, or concrete blocks joined with mortar. Most masonry dams are older gravity

dams, although a few are arch dams. Two methods have been used to build masonry dams: 1) placing shaped blocks of stone with mortar in the joints between them, and 2) binding various sizes of rock or concrete together with mortar.

Masonry dams may be classified 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 to be masonry dams. Masonry dams are built less often today because of their excessive cost of construction in comparison to modern concrete structures.

Low head dams constructed across streams and rivers present a safety hazard in the area just downstream of the dam. The whirlpools, hydraulic jumps, and eddies created from the discharging water are extremely dangerous to boaters and swimmers, and to dam safety inspectors. Low head concrete and masonry dams are prone to undermining at the toe because of excessive seepage or soil erosion and are subject to sudden failure of a segment of the structure.

The rest of this chapter describes visual inspection techniques for concrete and masonry dams and the elements of embankment dams constructed of concrete or masonry. Spillways and outfalls on concrete dams (and embankment dams) are covered in Chapter 6. The information on concrete spillways and outfalls also applies to concrete dams and should be used as necessary during visual inspections.

5.2 Inspection Procedure

Concrete and masonry dams are potentially more dangerous than embankment dams because when they fail, they do so quickly.

Some embankment dams have significant concrete structures (composite dams), making their inspection a combination of those for concrete/masonry and embankment dams. Basic procedures for inspecting concrete and masonry dams are like those for embankment dams, except that the crest and faces of the dams may be difficult to access. Therefore, inspector access and safety should be a primary concern at concrete and masonry dams.

The faces of concrete and masonry dams are often extremely steep, often vertical, and the upstream slope is usually damp and slippery. Access to the downstream face, toe area, and abutments may be problematic and require special equipment such as safety ropes or a boatswain's chair. Close inspection of the upstream face may also require a boatswain's chair or a boat. Without this equipment, inspection of all surfaces of the dam and abutments may not be possible.

Another method of inspection that may be used consists of video-recording the dam faces from a safe point using an elevated level of magnification on the camera. An inspector can zoom in on the surface areas and get a close-up view and recording of the dam. Filming should start at a discernable point, such as the top or toe of the dam face at the point of contact with the abutment. The camera should then pan slowly across the face of the dam with smooth parallel movements, continuing up or down the face after a sweep is made across the entire length of the dam. Sufficient overlap of adjacent, vertical areas is needed to ensure that all areas are covered. This technique can be deployed from a boat or on the ground for the upstream and downstream faces, depending on access. An inspector may have to move along the face if the dam is long. Every square foot of the dam surface can be recorded if an inspector is careful and methodical.

Inspectors should look for common ailments on concrete dams, including structural cracks, foundation or abutment weakness, deterioration from an alkali-aggregate reaction, cracks at construction joints (that is, the interfaces between concrete placements),

degradation because of spalling, and leakage. Special contraction joints are usually added to concrete and masonry dam bodies to accommodate volumetric changes, which occur in the structure after concrete placement, and are referred to as "designed" cracks. These joints are so constructed that no bond or reinforcing, except non-bonded waterstops and dowels, extend across the joint. Outlet system inspection should be emphasized during an inspection of tall concrete dams. Reading of an established monitoring network should be performed on a regular basis.

5.3 What to Look For

From a safety standpoint, the principal advantage of concrete and masonry dams is that they will not erode during overtopping (although the abutments or foundation could). Embankment slides and piping failures, typical of earth dams, are also absent in concrete and masonry structures.

It is important that owners of concrete and masonry dams are aware of the principal modes of failure and that they can distinguish between conditions that threaten the safety of the dam and those that only need repair. The design of a dam composed of concrete or masonry is much different than the design of an embankment dam, and, therefore, an inspection team may need a larger number of specialists.

Concrete and masonry dams fail for reasons different than embankment dams. Potential problems that may occur are discussed in this chapter. If any of these conditions are discovered during a visual inspection, the owner should obtain qualified professional help at once.

The essential items that are potentially hazardous at concrete and masonry dams are structural cracking, foundation or abutment weakness, and deterioration. The water in the reservoir exerts substantial hydrostatic forces on the structures, which in turn is transmitted to the foundations and abutments.

Damage or failure of a structural component may occur because of an external con-

dition such as an embankment slide, or a meteorological or a seismic event, which has subjected a structure to forces in excess of design. Damage to a structure may also be caused by the absence of a formal design, poor design, or poor construction. Structural problems usually contribute to the dam's susceptibility to failure during normal service.

5.4 Cracks and Structural Problems

A crack is a separation of portions of a concrete structure into one or more major parts and is usually the first sign of distress in the concrete. Cracks create openings in the concrete that allow further deterioration of the concrete. A concrete dam and its appurtenances must withstand considerable hydrostatic pressure from the reservoir and groundwater. Hydrostatic pressure acting along cracks through the concrete structure may exert dangerous uplift forces on the structure, leading to lateral propagation of the cracks, settlement, sliding of a part of the structure, and seepage. Inspectors should examine all visible concrete surfaces for any signs of cracking, structure movement, and water seepage through the dam.

Serious threats to concrete dams often involve cracks in the dam body, the abutments, or the foundation. Cracks may develop slowly at first, making it difficult to decide if they are widening or otherwise changing over time. Even if a crack itself does not present a serious threat, the mechanism causing the cracking should be measured and documented during a visual inspection. Or, many cracks may be visible within areas of a concrete surface, or the cracking may affect the entire surface. This condition is known as pervasive cracking. Pervasive cracking usually is a sign of concrete deterioration.

Cracking in concrete may be a visible sign of stress or movement, which the concrete cannot handle. The underlying cause of cracking may threaten the dam. For this reason, inspectors should make every effort to figure out the cause. An inspector must have a thorough understanding of the soil conditions in the foundation and the abutments when deciding on the cause of cracking.

5.4.1 Types of Cracking

There are two general types of cracking found in concrete structures: 1) individual cracks, and 2) pervasive cracks. A concrete structure may have one or a limited number

Table 5-1. ACI Standardized Terminology for Individual Concrete Cracks (ACI 2008)

Crack Characteristic	Descriptive Terms
Direction	<ol style="list-style-type: none"> 1. Longitudinal 2. Transverse 3. Vertical 4. Diagonal 5. Random
Width	<ol style="list-style-type: none"> 1. Fine: less than 0.5 mm 2. Medium: between 0.5 and 2 mm 3. Wide: over 2 mm
Depth	Measured depth

Note – Consistent with terminology used for cracking in embankment dams, some nomenclature for cracks in concrete dams differentiates cracks, on and parallel to the crest of a structure - termed longitudinal - from cracks on faces of the structure, which are designated as horizontal. ACI uses the term longitudinal to describe cracks in either location that are parallel to the crest.

of individual cracks that can be measured and documented during the visual inspection. Structural cracks usually occur either singly or in groups. Often, many cracks may be visible within areas of a concrete surface, or the cracking may affect the entire surface. This condition is known as pervasive cracking. Pervasive cracks tend to have different appearances depending on their cause. This type of cracking usually is a sign of some form of concrete deterioration.

5.4.2 Individual Cracks

The American Concrete Institute (ACI) Report No. 201.1R-08 “Guide to making a condition survey of concrete in service” (ACI 2008) has developed standardized terms to describe the appearance of individual cracks. These terms are listed in Table 5-1. It is recommended that an inspector uses this terminology to describe cracks in concrete dams and structures. After cracks have been classified as either individual or pervasive, inspectors should further describe the cracks using the ACI terminology in Table 5-1 for individual cracks, or the terminology described below for pervasive cracks.

5.4.3 Pervasive Cracks

The ACI uses three general classifications to describe extensive or pervasive cracking of concrete surfaces based on the shape of the cracks: 1) pattern cracking, 2) D-cracking, and 3) checking (see Figure 5-2). Therefore, widespread cracking should be further classified based on these shape descriptions. When the concrete exhibits extensive, pervasive cracking, the focus of the visual inspection should be the nature and extent of cracking rather than the dimensions of individual cracks.

Pattern Cracking

Pattern cracking is a form of pervasive cracking that consists of openings on a concrete surface in the form of a pattern and is caused by either shrinkage of concrete near the surface or a volumetric increase in concrete below the surface layer. Thermal stress, alkali-

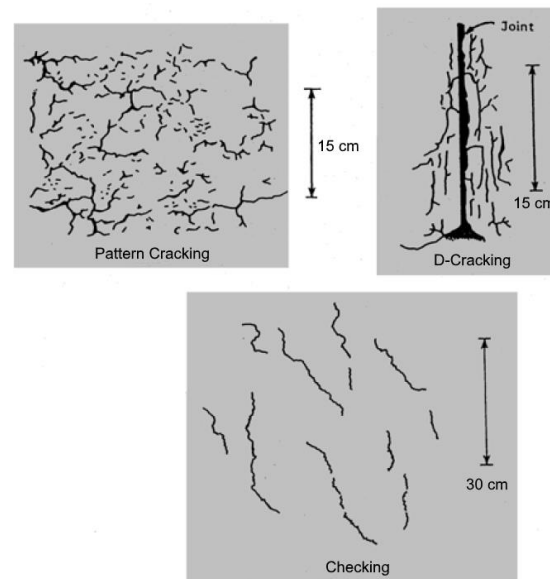


Figure 5-2. Illustration of the different forms of pervasive cracking.

aggregate reaction, and freeze-thaw actions cause changes in the volume of concrete.

Cement hydration in mass concrete causes heat resulting in expansion. This, followed by differential cooling and shrinkage of the outer surface, is a major cause of thermal cracking. Reactions within massive concrete sections may continue to generate hydration heat for decades. Restraint by rigid foundations or old lifts of concrete is also a factor. Thermal cracks are deep, often extending through thin sections.

Inspectors should be especially alert for thermal cracking in the massive concrete monoliths of concrete structures or dams (Figure 5-1). A pattern of hairline cracks in an

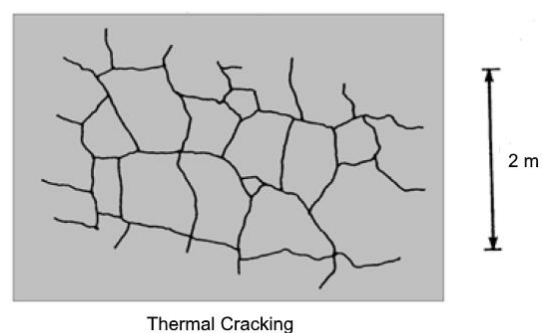


Figure 5-1. Illustration of thermal cracking in a massive concrete monolith.

orthogonal, blocky “dried mud puddle” configuration inside of galleries, usually accompanied by considerable leakage, is a sign of thermal cracking. Another sign of thermal cracking is the presence of vertical cracks continuous through walls, ceilings, and floors of transverse galleries resulting from cooling of concrete and restraint near the foundation. If thermal cracking is suspected, installing temperature gauges for thermal studies offers a means of collecting relevant data.

If available, the mix designs for the dam structure should be reviewed. Failure to use low-strength concrete for the interior and high-strength concrete on the exterior of the structure may have promoted thermal cracking.

Construction records should be checked for lack of such measures as the use of thinner lifts, controlling concrete placement temperature, replacement of cement with a pozzolan, and a reduced construction rate to deal with hydration heat.

An alkali-aggregate reaction can also cause pattern cracking. This condition is a reaction between soluble alkalis in the cement and silica in the aggregate and can cause abnormal expansion and cracking that may continue for many years. If an inspector sees pattern cracking in areas exposed to wet-dry cycles, the cause may be an alkali-aggregate reaction. Alkali-aggregate reactions are described more fully in the following subchapter on deterioration.

Freeze-thaw action is another common cause of pattern cracking and D-cracking; cracking increases geometrically with each freeze-thaw cycle. The freeze-thaw cycle starts when water enters pores, cracks, and joints in the concrete. When temperatures drop, water in the concrete freezes and expands, causing the concrete to crack. Water then enters the new cracks, and when temperatures drop again, the water freezes and expands, forcing the cracks to open wider. The pores and spaces in concrete must be saturated for freeze-thaw action.

Inspectors should examine areas of concrete exposed to moisture for damage from

freeze-thaw action. Exposed horizontal surfaces such as slabs and vertical walls near the water line are especially subject to freeze-thaw damage. Surfaces with a southern exposure can have accelerated damage because of daily freeze-thaw cycles. Use of entrained air helps protect concrete from freeze-thaw damage. Lack of entrained air in pre-1940 concrete elements, or an improper percent of entrained air, may have resulted in concrete that is vulnerable to damage.

D-Cracking

D-cracking is another form of pervasive cracking that exhibits fine parallel cracks at close intervals, usually along joints or edges. This type of pattern cracking is an early sign of damage from freeze-thaw action. Low-quality limestone aggregates are usually the cause of D-cracking, which is often seen at the exposed corners of slabs and walls formed by joints.

Checking

Checking consists of the development of fine, pervasive cracks on the surface of concrete; the cracks show no evidence of movement, are shallow and are closely spaced at irregular intervals. Cracks that display checking may be several meters long. Checking is usually caused by expansion and contraction or shrinkage of the concrete surface with alternating wet-dry periods. Rapid drying of newly placed concrete may also result in checking of the concrete surface.

Hairline Cracks

Hairline cracks are surface cracks and are less than a tenth of an inch wide and deep. They may consist of single, thin cracks, or pervasive cracks in a craze/map-like pattern. A small number of surface or shrinkage cracks is common and does not usually cause any problems. Minor or hairline surface cracking can be caused by weathering, the quality of the concrete that was applied, freezing and thawing, poor construction practices, chemical reactivity, and other factors as described above under pervasive cracks.

Hairline cracks are usually harmless and pose no immediate threat to the stability of

the spillway structure. This type of cracking should be noted and monitored on a routine basis for signs of additional deterioration. The location, orientation, length and width of the hairline cracks should be reported by an inspector.

The results of this minor cracking can be the eventual loss of concrete, which exposes reinforcing steel and accelerates deterioration. Minor surface cracking does not affect the structural integrity and performance of the concrete structure. However, even if a crack itself does not present a serious threat, the mechanism causing the crack may threaten the structure. Cracking in concrete may be a visible sign of stress or movement which the concrete cannot accommodate. The underlying cause of cracking may pose an immediate threat to the dam and should be determined. Therefore, inspectors should try to figure out the cause of any cracking that they find.

Structural Cracks

Inspectors should be able to recognize cracks that may affect the safety of the dam; these cracks are called structural cracks. A structural crack compromises the integrity of a concrete structure and therefore may pose a safety problem. In appearance, a structural crack may be:

- Diagonal or random with abrupt changes in direction
- Wide (greater than 5 mm.), with a tendency to increase in width
- Next to concrete that is noticeably displaced
- Occasionally narrow and diagonal, indicating inadequate design for shear stresses
- Long, single or multiple diagonal cracks with displacement and misalignment

Structural cracks usually result from movement of portions of a structure or over-stressing. External stresses may be caused by extreme or differential loading conditions, foundation settlement, voids under or along

the structure, seismic activity, design or construction errors, or deficiencies in the concrete materials. Flaws in structure design may result in stresses too great for the concrete to withstand. Concrete mixtures with deficient strength or elastic properties may crack under design stresses. Poor construction techniques may also be the cause of deficiencies that promote cracking. Deep and wide cracking is usually caused by stresses that are primarily from shrinkage, structural loads, or loss of foundation material.

Structural problems are indicated by cracking, exposure of reinforcing bars, large areas of broken-out concrete, misalignment at joints, undermining, and settlement in the structure. Rust stains that are noted on the concrete may indicate that internal corrosion and deterioration of reinforcement steel is occurring. Spillway floor slabs and upstream slope protection slabs should be checked for eroded underlying base material (undermining). Concrete walls and tower structures should be examined to determine if settlement and misalignment of construction joints have occurred. Cracks extending across concrete slabs which line open channel spillways or provide upstream slope wave protection can indicate a loss of foundation support resulting from settlement, piping, undermining, or erosion of foundation soils. Piping and erosion of foundation soils may be the result of inadequate under-drainage and/or cutoff walls.

Items to consider when evaluating a suspected structural crack are the concrete thickness, the size, and location of the reinforcing steel, the type of foundation, and the drainage provision for the structure. Floor or wall movement, extensive cracking, improper alignments, settlement, joint displacement, and extensive undermining are signs of major structural problems. Drainage systems may be needed to relieve excessive water pressures under floors and behind walls. Because of their complex nature, major structural repairs require professional advice and design. Part 2 of the India Dam Safety Inspection Manual describes repair operations in more detail. The method of repair will depend on

the size of the job and the type of repair required.

Cracks in concrete surfaces exposed to flowing water may lead to the erosion or piping of embankment or foundation soils from around and/or under the concrete structure. In this case, the cracks are not the result of a problem but are the detrimental condition which leads to piping and erosion. Seepage at the discharge end of a spillway or outlet structure may indicate leakage of water through a crack. Proper under-drainage for open channel spillways with structural concrete floors is necessary to control this leakage. Flows from underdrain outlets and pressure relief holes should also be watched and measured. Cloudy flows may be a sign that that piping is taking place beneath or next to the concrete structure. This could be detrimental to the foundation support.

Inspectors should look for structural cracks at areas of stress concentrations, such as corners of openings; contraction joints; areas of large temperature gradients, foundation and abutment material changes, slope changes, or direction changes in relation to the section of the structure. Temperature variations between the air and reservoir water in freezing weather can cause cracks extending from the structure crest down each face. Structural cracks often are wide, change widths with load changes or temperature cycles, or include significant leakage. Inspectors should compare their observations with the drawings, photos, or sketches from past inspections, and be alert for new cracks and for changes that differ from past trends.

Concrete surfaces next to contraction joints and subject to flowing water are of special concern, especially in chute slabs. The adjacent slabs must be flush, or the downstream slab should be slightly lower to prevent erosion or cavitation damage of the concrete and to prevent water from being directed into the joint during high-velocity flow.

Visual inspection of intake structures, trash racks, upstream conduits, and stilling basin concrete surfaces that are below the water surface is not usually possible during a

regularly scheduled inspection. Typically, stilling basins require the most regular monitoring and maintenance because they are holding ponds for rock and debris, which can cause extensive damage to the concrete surfaces during the dissipation of flowing water. Therefore, special inspections of these features should be performed at least once every five years by either dewatering the structure or when operating conditions permit. Investigation of these features using experienced divers is also an alternative.

5.4.4 Structural Cracking

Structural cracks are caused by overstressing of portions of the dam and are usually the result of inadequate design, poor construction techniques, or faulty materials. Structural cracks are often irregular, meaning they run at an angle to the major axes of the dam and may display abrupt changes in direction. These cracks may also have noticeable radial, transverse, or vertical displacement.

Overstressing in a concrete dam normally creates areas of distress and cracking that usually can be recognized visually during a visual inspection. Cracking, the separation of construction joints, changes in leakage rates, and differential movements are all indications of overstressing. The overstressing may occur along the foundation because of differential or extreme foundation movements or at any location in the concrete or masonry section of the dam. The overstressing may be caused by unusual external loading conditions, temperature variations, contraction joint grouting pressures, foundation movement, or excessive uplift pressure in the foundation or along unbonded lift lines.

The amount of displacement associated with structural cracking often varies along the length of a crack. This variation usually occurs because a part of the dam may have moved in relation to the original alignment. In any case, the presence of structural cracks could be a sign of the progressive failure of an abutment, the foundation, or the dam body. An inspector should record the location of the structural cracking, as well as the direction, width, and depth of the crack(s).

Qualified engineers should be brought in to examine structural cracks when they are discovered.

Masonry dams without adequate expansion joints may be subject to structural cracking in areas of stress. In some cases, one or more expansion joints may need to be added to the structure. This is a major design issue, and experienced structural engineers should be consulted to decide on the remedial measure. Cracks may be serious and should be evaluated to decide if they are active and the structural implications.

Inspectors should learn to recognize structural cracks that may affect the safety of the dam. A structural crack compromises the integrity of concrete and masonry structures and, therefore, may pose a safety problem. In appearance, a structural crack may be:

- Diagonal or random with abrupt changes in direction.
- Wide (greater than 5 mm), with a tendency to increase in width
- Next to concrete that is noticeably displaced
- Occasionally narrow and diagonal, which signals an inability to handle shear stresses
- Long, single or multiple diagonal cracks with displacement and misalignment

5.4.5 Joint Cracking

Contraction joints accommodate volumetric changes, which occur in the structure after concrete placement, and are sometimes referred to as “designed” cracks. These joints are built so that no bond or reinforcing, except non-bonded waterstops and dowels, extend across the joint. Cracking at contraction joints is common, and typically results in the formation of spalls (that is, a fragment, usually in the shape of a flake, detached from a larger mass) and minor leakage. Inspectors should examine all joints and look for cracking, spalling, and seepage.

5.4.6 Shrinkage Cracking

Shrinkage cracks often occur when irregularities or pockets in the abutment contact are filled with concrete and not allowed to cure fully prior to placement of adjacent portions of the dam. Subsequent shrinkage of the concrete may lead to irregular cracking at or near the abutment. Shrinkage cracks are also caused by temperature variation. During winter months, the upper part of the dam may become significantly colder than those portions that are in direct contact with the reservoir water. This results in cracks that extend from the crest for some distance down each face of the dam. These cracks will be at contraction joints if provided.

Shrinkage cracking can be caused by several factors, the principal ones being a badly designed mix (too much water, poorly graded fine aggregate having a high proportion of very fine material), and inadequate curing. The higher the percentage of fine material in a mix, the higher will be the water demand for a given workability.

All concretes and mortars shrink on drying out, and shrinkage will tend to widen cracks caused by other factors. The total shrinkage is made up of irreversible shrinkage and reversible shrinkage. On initial drying out an appreciable amount of the total shrinkage is irreversible, but after several cycles of wetting and drying the shrinkage becomes entirely reversible. Shrinkage can be partly restrained and crack width and spacing controlled using reinforcement.

Shrinkage cracks are usually confined to:

- non-structural members that have only nominal reinforcement for handling, such as precast units;
- floor toppings, screeds and rendering; and
- parapet walls with inadequate distribution steel.

Shrinkage stresses are often augmented by thermal contraction stresses. During winter months, the upper part of the dam may become significantly colder than those portions that are in direct contact with the reservoir

water. This results in cracks that extend from the crest for some distance down each face of the dam. These cracks will be at contraction joints if they are provided.

5.4.7 Thermal Cracking

During the setting and hardening process of concrete, considerable heat is evolved by the chemical reaction between the cement and the mixing water (hydration). This results in an appreciable rise in temperature in the concrete. The peak temperature, the time taken to reach the peak, and then cool down, depends on many factors. As the temperature of the maturing concrete rises the concrete expands, and as it cools down it contracts. The coefficient of thermal expansion (and contraction) depends on several factors, the principal ones being the type of aggregate and the mix proportions. With similar mix proportions, a limestone aggregate concrete has a significantly lower coefficient of thermal expansion than concrete made with, say, a flint gravel.

Thermal contraction cracking is caused by the inadequate distribution of reinforcing steel to take the stresses arising when the maturing concrete cools down from its maximum temperature. It can occur in parapet walls, retaining walls, and sometimes in floor slabs.

5.4.8 Pattern Cracking

This is really a special type of drying shrinkage cracking and can be very difficult, if not

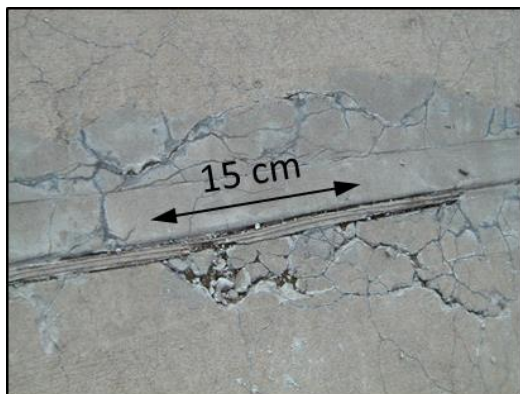


Figure 5-3. D-cracking along a contraction joint in a floor slab.

impossible, to eliminate completely. Pattern cracks usually are a sign of a problem, such as freeze-thaw action or some type of chemical reaction in the concrete.

The crack widths are usually in the range of 0.1 mm to 0.3 mm, and the depth seldom exceeds 0.5 mm. This type of cracking occurs in the very early life of concrete, but, because of the fineness of the cracks, is often not noticed or reported for months or even years. This type of cracking does not adversely affect the durability of the concrete.

5.4.9 D-Cracking

D-cracking is the progressive formation of a series of fine cracks at close intervals, often in random D-shaped patterns along a joint (Figure 5-3). D-cracking is caused by repeated freezing and thawing after moisture infiltration at the joint. As freeze-thaw cycles continue, the cracks extend farther away from the joint and become more severe, leading to a progressive structural deterioration of the concrete.

It usually takes several years for D-cracking to progress to the concrete surface where it first becomes visible as a series of small cracks, often preceded and accompanied by dark discoloration of the surface. However, air-entrainment of concrete during placement reduces the effect of freeze-thaw deterioration. Inspectors should especially look for D-cracking in concrete dams built without the use of air entrainment technology (those built before about 1970).

5.4.10 Abutment and Foundation Cracking

Concrete dams transfer large loads to the abutments and foundation. Although the concrete of the dam may endure, the natural terrain may crack, crumble, or move in a massive slide. If this occurs, support for the dam will be lost, and the dam will fail. Fault planes or weaknesses in the abutment may deteriorate with time, resulting in movement of the natural material in the abutment. Structural cracks in the concrete will be induced because of the movement in the abutment. This

situation creates the potential for failure of all or a part of the concrete or masonry structure, resulting in the release of reservoir water. If inspectors discover structural cracking, they should examine the foundation and abutments for signs of geological stresses or movement. Impending failure of the foundation or abutments is hard to detect because initial movements are often small.

Cracks in the abutments and foundation of a dam may signal a weak soil or rock zone, a settlement from consolidation, piping of soils or soluble rock from around or beneath the dam, or an overstressing caused by seismic activity or the load of the dam and reservoir. Foundation failure may allow the dam to start to move because of the force of the water behind the structure. In the worst-case scenario, the dam may collapse and allow the water to be released from the reservoir. Inspectors should look for signs of weak foundations, including cracking, dam movement, foundation seepage, and wet, soft foundation soils.

Abutment cracking is of primary concern at arch dams because the loadings on the dam are concentrated at the abutments. Inspectors should examine downstream appurtenant structures and abutment contact areas for signs of potential problems.

If cracking is discovered during a visual inspection of a concrete dam, inspectors should take the following actions:

- Photograph and record location, depth, length, width, and offset of the cracks. Note prominent cracks, cracking over large areas, and the trends that are developing.
- Look for structural damage, including misalignment, settlement, vertical and horizontal displacement.
- Look for any surrounding cracks.
- Classify and describe the cracks using the terminology defined earlier and that shown in Table 5-1.

If extensive new cracking is found, consider starting a crack survey to document all cracks in the structure and their characteristics

thoroughly. Contact a qualified dam safety professional if there is uncertainty about the severity of cracking or if the following conditions are found:

- A major new crack.
- Cracks that have changed significantly since the last inspection.
- Cracks are suggesting a movement that might be detrimental to the structure or to equipment operation.
- Significant leakage.
- Look for evidence of seepage or saturated soils in or below the cracks. Also, look for signs of foundation soil erosion. If there is an excessive amount of water flowing through a crack, recommend repairs. Check with a structural engineering specialist to select proper repair procedures.
- Decide if other dam structures, such as the spillways or outlets, could be affected by the cracking.
- Closely monitor the cracks for changes.
- Try to determine the cause of the cracking; this can help identify effective corrective actions.
- Consult a qualified dam safety professional to ascertain the cause of the cracking if it is severe or gets progressively worse. Serious cracking or repair operations may require lowering the reservoir level.
- Recommend proper corrective action be taken to repair, monitor, or replace the damaged areas. The recommended corrective actions should be consistent with an inspector's training and experience.

If instruments have been installed to measure the growth of severe cracks, the data may supply reasons for the cracking. Measurements of leakage and movement are particularly important for assessing the development of cracks, as well as for evaluating joints, which also are subject to leakage and movement. Reading of an established monitoring network should be performed on a regular basis.

5.4.11 Leakage through Cracks

Insignificant amounts of leakage through cracks in concrete and masonry dams, although unsightly, is not usually dangerous, unless accompanied by structural cracking. The worst effect may be to promote minor deterioration through freeze-thaw action. Increases in leakage might show that materials are being leached from the dam and carried away by the flowing water. A comprehensive analysis of the problem may be needed before it can be decided that repair is necessary for other than cosmetic reasons.

Inspectors should examine carefully all visible concrete surfaces for the presence of cracks. If water is seeping from cracks on the downstream face, an underwater inspection of the upstream face may be needed, depending on the severity of the problem and the amount of water seeping from the cracks.

5.4.12 Reporting Cracks

Inspectors should examine and report all types of cracks using the ACI terminology described earlier. Therefore, inspectors will have to be able to detect and describe cracks to be able to inspect concrete structures effectively. Structural cracks are serious and should be carefully evaluated and documented.

If the problem associated with the cracks is serious and potentially affects the integrity of the dam or its appurtenant works, a crack survey may be called for. A crack survey is an examination of a concrete structure for finding, recording, and describing cracks and of noting the relationship of the cracks with other signs of distress. A design drawing or inspection drawing is often used to record the location and extent of cracks in this type of survey. A grid system created with paint or chalk on a structure's surface can be used as an aid to determining crack locations.

A crack survey should catalog characteristics of the cracks such as length, width, direction, trend, depth, offset, and location. It should also describe the cracks based on the definitions presented above.

For monitoring purposes, measurement points should be marked, and the sharp edges of cracks should be protected with a thin coat of clear epoxy. This will prevent spalling or degrading of the edges which would give falsely high width measurements. Inspectors should use a comparator, feeler gage, or a handheld illuminated microscope to measure the width. A comparator is printed or inscribed with lines of various widths on a transparent background. An inspector places the comparator over a crack and matches crack width to a line. Two versions of comparators exist. One is a lighted magnifying glass with an eyepiece scribed with lines. The other is a transparent plastic card printed with lines.

Whenever possible, external cracks should be correlated with internal cracks. Where repairs have been made to the concrete, crack surveys are difficult to perform and may be unreliable because cracks beneath the repairs may be a sign of degradation at greater depths. It is significant, however, to note whether new cracks have developed in the repaired concrete. Such cracks may indicate continuing structural deterioration.

Other conditions or deficiencies are often associated with cracking, such as leakage, deposits from leaching or other sources, and spalling of crack edges. These conditions should also be reported. Inspectors should always look for seepage into or out of cracks. Water from seepage or leakage may compound the problem, leading to further degradation, including:

- The development of excessive hydrostatic pressures on some portions of the structure
- Attacking the concrete chemically
- Freeze-thaw damage to concrete
- Erosion or solution of the foundation material
- Leaching of the concrete

Sometimes the leakage source can be determined by comparing leakage water temperature with ground water and reservoir

temperatures. Dye tests are another means of identifying the leakage sources. Approved dyes can be placed in the water upstream of the structure, in drill holes, or in other accessible locations. The location and time the dyes appear downstream can find the sources and velocity of leakage. Chemical analysis of leakage water and deposits may be advisable if other problems begin to develop.

The most common leakage measuring devices include a container and stopwatch, weir, flume, and flow meter. A container and a stopwatch may be used to measure the leakage from a crack if the water can be conveniently contained. It may be necessary to use a plate or other device to get the leakage to spring free from the concrete surface and into the container. Sometimes the seepage water may have to be collected or measured at a point downstream of the source to make it convenient to do so. It is not always easy to collect and measure water flow rate from seeps; an inspector may have to be creative to implement a collection and measurement procedure.

Movement between adjacent concrete surfaces or between concrete surfaces and the foundation can be measured with survey instruments, foundation baseplates, settlement sensors, inclinometers, extensometers, tiltmeters, plumb lines, measurement points, calibrated crack monitors, joint meters, embedded strain meters, stress meters, and temperature gauges. Inspectors should note all instances when monitoring equipment reveals enlargement or other changes in a crack. Also, they should examine other instrumentation measurements for evidence of conditions that may have caused changes in the crack.

If cracking is discovered during a visual inspection of a concrete spillway or outlet, the following actions should be taken:

- Photograph and record location, depth, length, width, and offset of the cracks.
- Note prominent cracks, cracking over large areas, and the trends for specific cracks.

- Look for structural damage, including misalignment, settlement, vertical and horizontal displacement.
- Look for any surrounding cracks.
- Classify and describe the cracks using the terminology defined above.
- If extensive new cracking is found, consider starting a crack survey to document all cracks in the structure and their characteristics thoroughly. Contact a qualified dam safety professional if there is uncertainty about the severity of cracking or if the following conditions are discovered:
 - a. A major new crack
 - b. A crack(s) that has changed significantly since the last inspection
 - c. Cracks suggesting movement that might be detrimental to the structure or to equipment operation
 - d. Significant leakage
- Look for evidence of seepage or saturated soils in or below the cracks. Also look for signs of foundation soil erosion. If there is an excessive amount of water, or water which cannot be handled by the drainage system is flowing through a crack, recommend repairs. Check with a concrete specialist to identify appropriate repair procedures.
- Determine if other dam structures, such as the embankment, could be affected by the cracking in the spillway.
- Closely monitor the cracks for changes.
- Try to determine the cause of the cracking; this can help identify effective corrective actions.
- Consult a qualified dam safety professional to determine the cause of the cracking if it is severe or gets progressively worse. Serious cracking or repair operations may require lowering the reservoir level.
- Recommend the corrective action be taken to repair or to replace the damaged

spillway areas. The recommended corrective actions should be consistent with an inspector's training and experience.

If instrumentation has been installed to monitor serious cracks, the data may supply reasons for the cracking. Measurements of leakage and movement are particularly important for evaluating cracks, as well as for evaluating joints, which also are subject to leakage and movement.

Any recommendations an inspector may make for simple corrective actions should be reviewed by qualified dam safety professionals. Extensive corrective actions that may be taken in response to inspection findings include:

- For cracks that may be leaking but there is not a high hydrostatic head, treatment may consist of grouting the crack by injecting either an elastomeric filler (if crack movements are expected) or a rigid epoxy mortar.
- For cracks where leakage is accompanied by high hydrostatic pressure, installation of a drainage system may be necessary.
- If a structural analysis shows a crack has affected the structure's stability, post-tensioning between components of the structure or between the structure and foundation rock or anchors may be needed.
- Collapsed slabs and wall may need complete replacement and foundation repair.
- Concrete conduits may need to be replaced if the damage is severe. Conduit linings may also be applicable.

Repair materials that may be used include epoxy grout, methacrylates, polymerized concrete or mortar, fiber-reinforced concrete, and low water-cement ratio concrete.

5.5 Deterioration

Deterioration is any adverse change on the surface or in the body of a dam that causes the structure to separate, break apart, or lose strength. Deterioration is normally caused by the forces of nature such as wetting and drying, freezing and thawing, oxidation, decay,

and erosive forces of wind and water. Activities of humans can also contribute to deterioration by altering the chemical composition of water through the application of chemicals on or near a dam. A subjective evaluation of the extent and effects of deterioration should be made. Sometimes deterioration will be extensive enough to cause other detrimental conditions such as structural failures of concrete or masonry.

The greatest weakness of masonry dams is the tendency for the masonry or mortar between blocks to deteriorate with resultant leakage, deformation, and general disintegration. Other than that, deterioration of the structural components masonry dams is similar to what takes place in concrete dams. For this reason, procedures for inspecting concrete dams apply to masonry dams as well. With these points in mind, the remainder of this chapter refers mostly to concrete dams and, unless stated otherwise, the discussions apply to both concrete and masonry dams.

5.5.1 Concrete Deterioration

Concrete deterioration is a progressive reduction in properties that may make concrete no longer serviceable for its intended use. This may be a physical "removal" of materials from the surface of the structure leading to a reduced cross section or an internal change in strength, modulus of elasticity, Poisson's ratio, or density that reduces its overall structural load-carrying capacity. For example, surface deterioration and loss of material caused by freeze-thaw deterioration of concrete can lead to a reduced cross section of a concrete dam. The reduced cross section increases the stresses of the remaining section proportionately to the amount of material removed. As another example, internal expansion of a concrete structure caused by alkali-aggregate reaction (AAR) may reduce the strength and modulus of elasticity of the entire structure. Swelling and cracking of concrete outlets or spillways caused by AAR leads to reduced structural performance, and the cracking may accelerate other deterioration mechanisms, such as freeze-thaw deterioration.

The joint effect of deterioration and cyclic loading may be very detrimental to concrete and mortar. Cyclic loads, even at low stresses, may cause permanent strains to accumulate. It is possible that, if the loads are high enough in comparison to the concrete strength, these strains may cause failure even at small stresses.

There are several known processes of concrete deterioration. These include physical and chemical processes acting on the inherent structure of the cement and concrete and processes related to “flaws” in construction that may affect the safety of the structure. The following sections describe typical deterioration mechanisms.

Freezing and Thawing Deterioration

A freeze-thaw attack is a form of internal disruption of the concrete paste caused by the formation of ice crystals in saturated concrete. Freeze-thaw deterioration is particularly severe in the northern mountainous zones of India, which may experience 50 to 100 cycles of freeze-thaw each year.

Deterioration is especially severe in the splash zone of hydraulic structures experiencing freeze-thaw cycles. Ice expands about nine percent upon freezing, causing forces of up to 200,000 kPa, which is enough to crack concrete if it is not protected against this action. Freeze-thaw deterioration is a progressive attack, starting from the exterior of the concrete and moving inward. As some of the concrete fails and is removed by spalling, the depth of freezing progresses inward.

Alkali-Aggregate Reactions

AAR is a chemical reaction between the alkalis in cement and certain “reactive” aggregates that produces a gel that will expand in the presence of water. AAR gel is sufficiently expansive to fracture aggregates and concrete paste and cause the concrete to swell and crack. Dams experiencing AAR have been known to swell as much as one foot in height and length.

AAR occurs in two basic forms: alkali-silica reaction (ASR) and alkali-carbonate reaction. ASR can happen in concrete containing

cement having an alkali content greater than 0.6 percent and glassy siliceous volcanic rocks and other potentially deleterious rock types such as chert, opal, shale, and certain quartzitic rock.

Typical AAR deterioration results in swelling and cracking of the concrete, accompanied by a decrease in strength and modulus of elasticity. The cracking also provides avenues for moisture to enter the concrete and contribute to accelerated freeze-thaw attack in cold climates. Methods to prevent ASR include identifying potentially reactive aggregates using petrographic techniques, limiting their use, and specifying low-alkali cement and pozzolans.

Sulfate Attack

Sulfate attack is both a chemical and physical attack of the internal microstructure of the concrete paste. Sulfates in groundwater and soil can migrate into the concrete and cause an expansive disruption of the paste, leading to cracking and failure of the concrete. Severe sulfate attack can disrupt and fail concrete in as little as 5 years or less.

Physical sulfate attack involves saturation of porous concrete with sulfates that, under certain drying conditions, can precipitate as crystals within the cement matrix, disrupting its internal structure. Chemical sulfate attack is a chemical reaction between sulfates and cement hydration products that forms expansive compounds and causes dissolution of the paste. Chemical sulfate attack is common where high evaporation rates cause sulfates to concentrate in the upper soil strata. Most sulfate attacks in concrete happen when the cement has a large amount of tricalcium aluminate.

Abrasion-Erosion and Cavitation Damage

Abrasion-erosion damage is a physical wearing of the concrete by water-born sediments, gravels, and rocks. Abrasion erosion damage can be caused both by concrete with low strength and poor aggregates and by design related problems that may sweep rocks and sediments from downstream back into spillway and outlet works stilling basins, resulting

in particles abrading the surface in a roller-mill fashion. Structural damage from abrasion erosion damage can be quite severe at large dams.

Cavitation damage is caused by the formation and subsequent collapse of sub-atmospheric water vapor “bubbles,” releasing tremendous positive pressures on the surface of the concrete. Cavitation damage is a concern for high-velocity water flows in spillways and outlets. Cavitation is aggravated by aggregate popouts, construction related offsets, and deposits of carbonates (leaching product from concrete). In outlet works, cavitation can be caused by insufficient air supply to gates, defective construction, and sometimes by the way the gates are operated.

Both abrasion-erosion and cavitation damage can be reduced by using high-strength concrete, changing the design and operation of spillways and outlets, and eliminating of significant construction offsets. Modern repair materials with compressive strengths of up to 100,000 kPa now give greater abrasion-erosion resistance to areas prone to damage from abrasive particles and rocks.

5.5.2 What to Do

If deterioration of concrete surfaces is found during a visual examination of a structure, inspectors should:

- Photograph and record location, type, and extent of the deterioration.
- Note prominent features, and whether cracking is also present.
- Look for structural damage, including misalignment, settlement, vertical and horizontal displacement.
- Look for any surrounding damage to structures or foundation. Inspectors should look closely for changes in the spillways and outlet structures that may be affected by structural damage to the dams. Items to check include vertical, horizontal and lateral displacements, structural cracking, and tilting of spillway walls.
- Classify and describe the deterioration using the terminology previously defined.
- If deterioration is extensive, consider starting a condition survey or surface mapping to document all problems in the structure and their characteristics thoroughly. Contact a qualified dam safety professional if there is uncertainty about the severity of deterioration.
- Look for evidence of seepage or saturated soils in or below the dam and on the abutments. Also, look for sign of foundation soil erosion. If there is an excessive amount of water, or water, which cannot be handled by the drainage system, is flowing through a crack, recommend repairs. Check with a qualified structural engineer to identify proper repair procedures.
- Determine if other dam structures, such as the spillway or outlet, could be affected by the deterioration that is observed.
- Closely monitor the problems for changes.
- Try to figure out the cause of the deterioration; this can help plan effective corrective actions.
- Consult a qualified dam safety professional to decide on the reasons for the problem if it is severe or becomes progressively worse. Serious deterioration or repair operations may require lowering the reservoir level.
- Recommend proper corrective action be taken to repair or to replace the damaged spillway or outlet areas. The recommended corrective actions should be consistent with an inspector’s training and experience.

Although outlet system deterioration is usually not a problem at concrete dams, the frequency of such damage is higher because of the greater average hydraulic head. Visual inspection of the outlet system should be emphasized during an inspection of tall concrete and masonry dams.

5.6 Other Deterioration Mechanisms

Several other mechanisms may act on concrete and masonry structures and either cause damage themselves or accentuate other more common forms of deterioration. These forms of deterioration include acid attack, chloride contamination (resulting in reinforcing steel corrosion), wetting and drying volume change, and carbonation shrinkage. Though these forms of deterioration are severe, most dams are not significantly affected by them.

India's dams are not normally exposed to severely corrosive environments or environments high in chloride. Damage as a result of corrosion of reinforcing steel is often associated with defective construction practices resulting in inadequate concrete thickness over reinforcement. However, there is potential for corrosion of trunion pins in spillway gates caused by carbonation-induced shrinkage cracking and a subsequent drop in passive resistance to corrosion provided by the high pH of cement paste. In addition, aging concrete and masonry dams have suffered from increased porosity of the cement paste because of leaching of calcium hydroxide.

5.7 Ineffective Internal Drainage Systems

Ineffective or nonexistent foundation and internal drainage systems in concrete and masonry dams can create excessive hydrostatic pressures along the base of the dams and within the dam bodies. These extreme pressures could cause structural failure of a dam by sliding and extensive cracking within the dam body that could lead to structural failure.

Where they already exist, the monitoring and maintenance of internal drains is essential. Regular drain flow observations must be part of any inspection program. Accumulation of deposits in the drains is checked by probing to determine the location and characteristics of the obstructing material.

When uplift forces are steadily increasing or when seepage flows have decreased the need for cleaning drains or drilling new ones

is warranted. When drains become so obstructed as to impair their function, and the deposits are soft, they can be cleaned by washing. However, this is often only a temporary remedy. A better solution is to re-drill the old drain or to drill new drains. Where drains do not exist or are inadequate, new ones can often be drilled into the foundation from existing galleries or from the downstream face.

5.8 Special Inspection Techniques and Requirements

Access and safety are concerns that need to be planned for in advance of a visual inspection. The conditions normally met at concrete dams make it difficult to gain close access to all features.

The faces of concrete dams are often vertical, and the site is often a steep-walled rock valley. Access to the downstream face, toe area, and abutments may be challenging and usually demands special equipment such as safety ropes or a boatswain's chair. Close visual inspection of the upstream face may also need a boatswain's chair or a boat. Without this equipment, visual inspection of all surfaces of the dam and abutments may not be possible.

A boat may be needed to access the upstream face that is above the water. In-channel dams such as low head dams, and areas downstream of large outfalls are dangerous and demands extreme caution during visual inspections. The high-velocity water current, whirlpools, hydraulic jumps, and eddies that form in these areas can create conditions that trap and sink boats and swimmers. Inspectors should always wear life preserver jackets when using a boat. Experienced underwater divers may be needed if the submerged part of the upstream face must be inspected. Radio communication between the diver and an experienced inspector on the surface is preferred during this exercise.

Regular visual inspection with a pair of powerful binoculars can initially detect areas where the change from surrounding areas is occurring. When these changes are noted, a

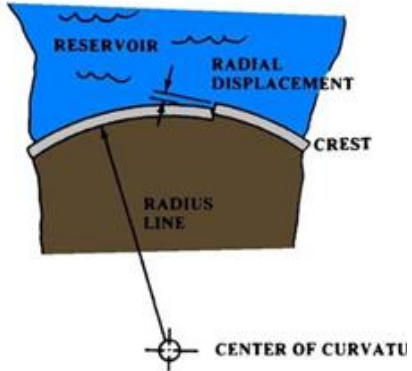
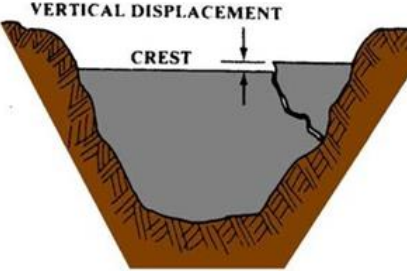
detailed close-up inspection should be performed. Any questionable condition demands immediate evaluation by a qualified dam safety professional. Because the failure of concrete dams can occur suddenly, even a hint of a problem must be evaluated.

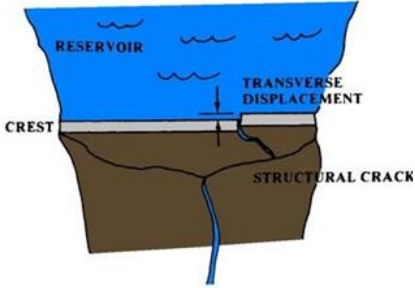
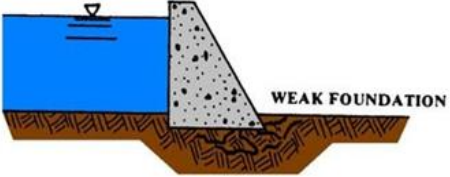
Another technique that can be used is to video record of the entire structure. A high-power zoom lens can be used to get close-up video of the dam faces and discharge structures. The tapes can then be examined closely in the office for visual problems. Problems that are detected may then require closer visual inspection in the field. Problems that may be met with this technique include gaining access to points where filming will be effective and obtaining full and complete coverage.

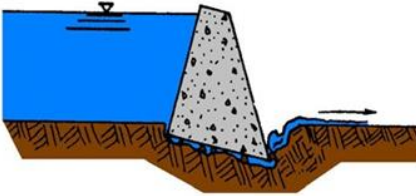
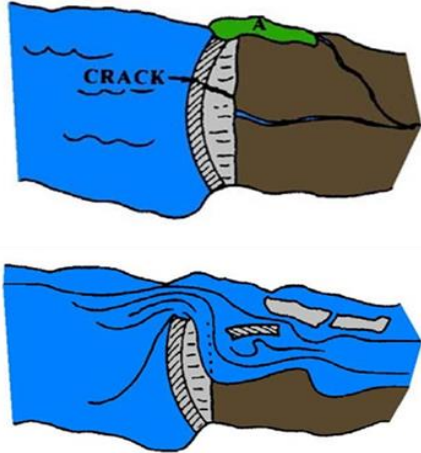
5.9 Concrete and Masonry Dam Inspection Sketches

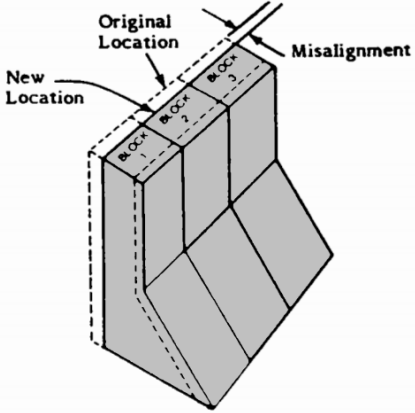
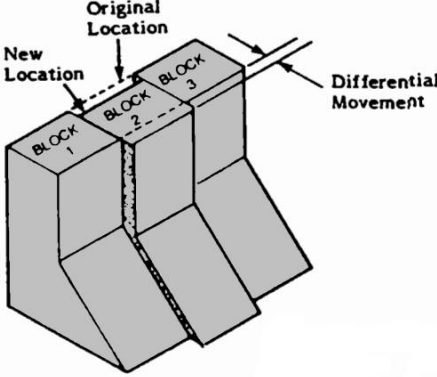
Sketches of conditions that might be found at concrete and masonry dams during a visual inspection, the hazards created, and possible remedial measures are presented in Table 5-2. While most of the conditions shown in the drawings can be corrected by routine and periodic maintenance carried out by the dam owner, some of the problems are of a nature that threatens the safety and integrity of the dam and need the attention of qualified engineers and geologists to decide on remedial measures. Depending on the severity of the condition, the dam owner may need to take immediate action to prevent the condition from worsening, including contacting repair contractors and notifying local disaster management authorities.

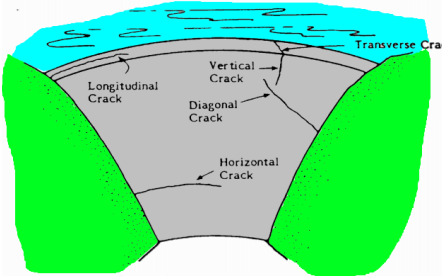
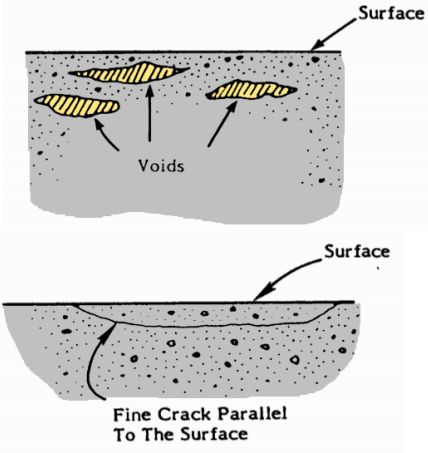
Table 5-2. Sketches of problems that are found at concrete and masonry dams, the hazards created, and remedial measures

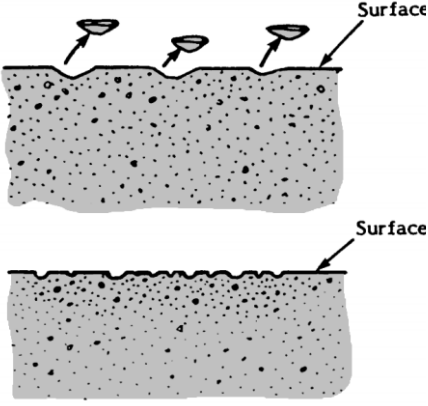
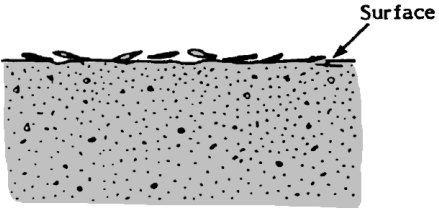
Problem	Probable causes	Hazards created	Remedial measures
 <p>Radial Displacement and Cracking of Arch Dam</p>	<ol style="list-style-type: none"> Sliding of a section of the dam because of excessive hydrostatic forces. Failure at an abutment resulting in downstream movement of a part of the arch. 	<ol style="list-style-type: none"> If the crack and movement of the dam are significant, catastrophic failure is possible. Lowering of the reservoir level reduces hydropower production and availability of irrigation and municipal water supply. 	<ol style="list-style-type: none"> Measure crack growth closely and decide on the severity of the problem. Check carefully for leakage through cracks to help decide on the seriousness of the problem. Immediate lowering of the reservoir level to reduce hydrostatic forces. Notification of disaster management authorities if the failure of the dam is possible.
 <p>Vertical Displacement and Cracking</p>	<ol style="list-style-type: none"> Foundation settlement or piping may lead to structural cracking with vertical displacement. 	<ol style="list-style-type: none"> Cracking in concrete may be a visible sign of stress or movement, which the concrete cannot tolerate. The underlying cause of cracking may pose an immediate threat to the dam; therefore, every effort to figure out the cause of the problem. 	<ol style="list-style-type: none"> Grouting can stop or reduce seepage and piping, which should end settlement, and fill voids in the foundation. Cracks need to be repaired and monitored with crack meters to measure growth. Seepage needs to be carefully measured.

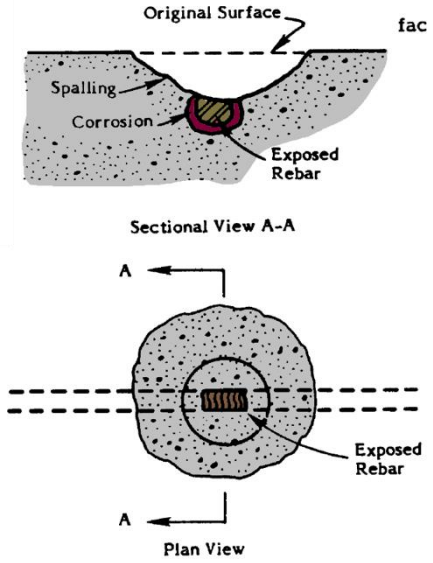
Problem	Probable causes	Hazards created	Remedial measures
 <p style="text-align: center;">Transverse Displacement</p>	<p>1. Structural crack with transverse displacement and significant seepage.</p>	<p>1. Leakage through cracks in concrete dams, although unsightly, is not usually dangerous, unless accompanied by structural cracking.</p> <p>2. The worst effect may be to promote minor deterioration due to the elements through freeze-thaw action.</p>	<p>1. Repair cracks by filling with proper material that depends on the type, size, and extent of cracking. \Install crack meters to check the continued development of cracking.</p>
 <p style="text-align: center;">Cracks in Abutments and Foundation</p>	<p>1. Cracks in the abutments and foundation of a dam may be a sign of a weak soil or rock zone, settlement due to consolidation, piping of soils or soluble rock from around or beneath the dam, or an overstressing caused by seismic activity or the load of the dam and reservoir.</p>	<p>1. Continued internal erosion from seepage or leakage increase. In the worst-case scenario, the dam may collapse and allow an uncontrolled released of impounded water.</p>	<p>1. Reduce seepage/leakage through abutments or foundation by grouting or slurry cutoff walls.</p> <p>2. Monitor seepage/leakage carefully to see if flow rates are increasing or after remedial measures have been taken, flow rates have been reduced.</p>

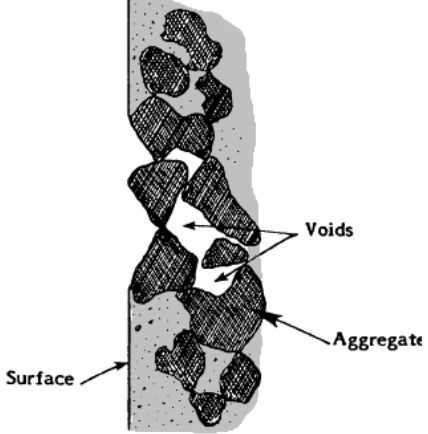
Problem	Probable causes	Hazards created	Remedial measures
 <p style="text-align: center;">Downstream Movement or Tilting of Dam</p>	<ol style="list-style-type: none"> Weak foundation soils may result in dam movement and seepage. Foundation failure may allow the dam to start to move because of the force of the water behind the structure. 	<ol style="list-style-type: none"> In the worst-case scenario, the dam may collapse and allow an uncontrolled release of impounded water. 	<ol style="list-style-type: none"> If a significant movement has taken place and seepage is great, the reservoir level should be lowered at once. Buttresses, piling, and other structural reinforcement may be needed to support the dam.
 <p style="text-align: center;">Weakness in Abutment</p>	<ol style="list-style-type: none"> A weak area in the left abutment is subjected to large stresses from this arch dam. Fault planes or weaknesses in the abutment may deteriorate with time, resulting in movement of the natural material in the abutment. Structural cracks in the concrete will be induced because of the movement in the abutment. 	<ol style="list-style-type: none"> Structural cracks in the concrete will be induced because of the movement in the abutment. This situation creates the potential for failure of all or a part of the concrete structure resulting in breaching of the dam. Although the concrete of the dam may endure, the natural terrain may crack, crumble, or move in a massive slide. If this occurs, support for the dam will be lost, and the dam will fail. 	<ol style="list-style-type: none"> If continued abutment movement is detected the reservoir level must be lowered at once to prevent further displacement. Geotechnical/structural measures need to be investigated to reinforce abutments.

Problem	Probable causes	Hazards created	Remedial measures
 <p>The diagram shows three concrete blocks labeled BLOCK 1, BLOCK 2, and BLOCK 3. Dashed lines indicate their 'Original Location' in a straight line. Solid lines show their 'New Location', which are shifted relative to each other, creating a 'Misalignment'. Arrows point to the original and new positions.</p> <p>Misalignment of Blocks</p>	<ol style="list-style-type: none"> Inadequate foundation support. Misalignment is any variation from the original structural configuration and will be detected by sighting techniques at the crest of the dam. 	<ol style="list-style-type: none"> Misalignment in and of itself is not a hazard. Small misalignments are of little concern and will not have an adverse impact on the stability of the dam. Misalignment becomes a hazard when it has an adverse effect on the entire structure or on one or more of its parts. 	<ol style="list-style-type: none"> Movements need to be monitored closely. Excessive movement can be controlled by construction of buttresses or added mass on the downstream side of the dam.
 <p>The diagram shows three concrete blocks labeled BLOCK 1, BLOCK 2, and BLOCK 3. Dashed lines indicate their 'Original Location' in a straight line. Solid lines show their 'New Location', where they have moved downwards and outwards from each other, creating 'Differential Movement'. Arrows point to the original and new positions.</p> <p>Differential Movement of Blocks</p>	<ol style="list-style-type: none"> Differential movement of blocks can be caused by a) abutment or foundation settlement or displacement, b) chemical reactions in the concrete, c) applied loadings of exceptional size (e.g., uplift pressures, earthquake, extreme temperature variations). The differential movement will be detected by sighting techniques at the crest of the dam. Differential movement most often appears as deflection at joints between adjacent blocks. 	<ol style="list-style-type: none"> Movement in and of itself is not a hazard. Small movements are of little concern and usually are considered in the design of the dam. Movement becomes a hazard when it has an adverse effect on the entire structure or on one or more of its parts. Significant changes – either in amount or in direction – should be evaluated at once by experienced, qualified engineers. 	<ol style="list-style-type: none"> Movements need to be monitored closely. Excessive movement can be controlled by construction of buttresses or added mass on the downstream side of the dam.

Problem	Probable causes	Hazards created	Remedial measures
 <p style="text-align: center;">Concrete Cracking</p>	<ol style="list-style-type: none"> Cracking in a concrete dam occurs when tensile stresses develop that exceed the tensile strength of the concrete. These stresses may occur because of imposed loads on the structure or because of volumetric changes in the concrete. Volumetric change in mass concrete can be caused by changes in temperature or by a chemical reaction within the concrete 	<ol style="list-style-type: none"> Cracks typically caused by drying shrinkage, thermal movement, or other causes usually are minor and result in few problems. However, in some cases, a crack will widen over time and result in water seepage or the loss of structural integrity. Many cracks will be found during the course of an inspection, but not all cracks are serious. However, cracking should be watched closely because cracks can create openings in the concrete that allow other types of deficiencies to develop. 	<ol style="list-style-type: none"> Trend is extremely important in monitoring cracking. The trend of a crack is its history of change. Studying prior reports before an inspection begins will enable an inspector to focus on how cracks have changed--that is, whether they have become longer, wider, or deeper, changed direction, or are unchanged. Documenting changes will enable future inspectors to do the same thing. Measuring devices, or reference points, are sometimes permanently placed across a crack to measure the change in width over time. This type of instrumentation is covered in the <i>Guidelines for Instrumentation of Large Dams</i> (CDSO 2017b).
 <p style="text-align: center;">Drummy Concrete</p>	<ol style="list-style-type: none"> Concrete has a void, separation, or other weakness – usually a thin surface layer separated from the mass. Caused when finishing operations occur too early. 	<ol style="list-style-type: none"> The delamination problem caused by drummy concrete can be quite widespread and affect large zones of a surface. The presence of voids and fine cracks can worsen effects of the freeze-thaw action. 	<ol style="list-style-type: none"> Drummy-sounding areas are easily detectable by hammer or chain dragging. Depending on their severity and surface use (such as exposure to wheel loads and heavy traffic), these zones are likely to detach sooner than from a sound surface. To achieve a high-quality surface, remove the defective concrete to a depth where only sound concrete remains. Proper removal of unsound concrete by suitable methods such as shot blasting, grinding, or hydro-demolition, is essential if repairs are to be successful.

Problem	Probable causes	Hazards created	Remedial measures
 <p style="text-align: center;">Concrete Popouts</p>	<ol style="list-style-type: none"> 1. A popout is a hole in a concrete surface left after an aggregate particle has expanded and worked itself loose because of a) a physical reaction, or b) a chemical reaction: 2. The physical expansion popout occurs when a lightweight, porous rock freezes, expands, and then fractures. 3. The alkali-aggregate popout (chemical popout) occurs when the alkalis in the portland cement react chemically with the silica in some fine sands, causing an expansion of the silica particle. 	<ol style="list-style-type: none"> 1. Popouts do not in any way decrease the life of a concrete surface. Popouts will not affect the structural serviceability of the surface. Usually, popouts are tolerated or overlooked, especially if their size and frequency are not excessive. However, surfaces with many popouts will be aesthetically displeasing. 	<ol style="list-style-type: none"> 1. Surfaces with popouts can be repaired. A small patch can be made by cleaning out the spalled particle and filling the void with dry-pack mortar, epoxy mortar, or another patch material. If the popouts are too impractical to patch individually, a thin bonded overlay may be used.
 <p style="text-align: center;">Concrete Spalling or Scaling</p>	<ol style="list-style-type: none"> 1. Freezing causes the water in the capillaries of the concrete to expand, creating pressure. Repetitive freeze-thaw cycles cause stresses which can break off the surface concrete. 2. Improper concrete finishing can contribute to the premature spalling of concrete surfaces. 	<ol style="list-style-type: none"> 1. Concrete spalling not only looks terrible, but it is potentially dangerous too. Over time, and with increased exposure to the elements, untreated pieces of concrete may fall from the structure. 2. The hazard is caused by the piece of concrete to falling and damaging property, or even worse, hitting a person walking below. 	<ol style="list-style-type: none"> 1. Repairing concrete surfaces affected by spalling requires covering the entire area with a polymer-modified cementitious overlay that is colored to match the existing surface. 2. Once the overlay cures, a waterproofing sealer should be applied to prevent the problem from reoccurring.

Problem	Probable causes	Hazards created	Remedial measures
 <p>Concrete Deterioration from Reinforcing Steel Corrosion</p>	<ol style="list-style-type: none"> <li>1. Embedded reinforcing steel normally is protected by the concrete. When the concrete deteriorates, however, water can reach the steel and cause it to corrode. <li>2. The oxide produced during corrosion results in an increase in volume, which causes the overlying concrete to crack and spall. The most well-known form of corrosion is rust. 	<ol style="list-style-type: none"> <li>1. Corrosion of steel reinforcing bars can weaken the concrete structure and cause it to fail. <li>2. Corrosion of reinforcing bars hastens spalling and cracking. 	<ol style="list-style-type: none"> <li>1. Damage can be repaired by removing and then replacing deteriorated concrete and badly corroded steel reinforcing bars.

Problem	Probable causes	Hazards created	Remedial measures
 <p>(Sectional View)</p> <p>Honeycombin</p>	<ol style="list-style-type: none"> 1. Honeycombs are voids left on the concrete surface when the mortar does not fill spaces between the coarse aggregate particles. 2. This is a construction defect caused by poor work practices such as inadequate concrete mixing, segregation because of improper placement or insufficient vibration after placement of concrete in the forms. 	<ol style="list-style-type: none"> 1. The resulting defect is either simply accepted by the dam owner, or the contractor is required to remove the flawed concrete and rebuild that portion of the structure. 	<ol style="list-style-type: none"> 1. These defects, if minor, can be repaired by removing the flawed concrete and replacing it with dry pack, epoxy-bonded replacement concrete, or replacement concrete. 2. Some minor defects resulting from form movement or failure can be repaired with surface grinding.

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Chapter 6. INSPECTING SPILLWAYS AND OUTLETS

The purpose of a dam safety inspection is to identify deficiencies that potentially affect the safety of the dam. An inspector should develop a systematic procedure for visually checking a dam to ensure that all features and areas are examined and to minimize the amount of time spent on-site. This chapter focuses on the visual inspection of dam spillways and outlet structures. These structures are part of the appurtenant works of embankment and concrete dams.

Information presented in this chapter helps identify common problems that affect the performance of spillways and outlets in dams, and outline visual inspection procedures. The general technique for visually inspecting spillways and outlets is to examine each feature up close. All visible defects should be measured, evaluated, and recorded. Some form of report or documentation with recommendations for corrective action is then prepared for the dam owner's project files. Some spillways and outlets may be difficult to access and may require special equipment to carry out a visual inspection.

6.1 Types of Spillways and Outlets

The spillway system consists of the structures over or through which base inflows and flood flows are safely discharged. If the flow is controlled by gates, it is a controlled spillway; if the elevation of the spillway crest is the only control, it is an uncontrolled spillway.

Inspectors should review the dam owner's project files for design capacity calculations to make sure that the dam spillway system can safely handle the inflow design flood. They should also look for signs of high water levels when they are carrying out their visual inspections.

Spillways typically include all or most of the following four components, each serving a different function: 1) entrance channel, 2)

control section, 3) outlet channel, and 4) terminal structure. The entrance channel conveys water from the reservoir to the control section and is usually required except for drop inlet spillways located in the reservoir and overflow spillways on concrete dams. The control section governs the spillway discharge. Control sections may be orifice-like openings, conduit entrances, or a crest in the form of a shaped weir or a sill. They may be either unregulated or regulated by gates, flashboards, and valves. The outlet channel conveys and returns the water to the stream beyond the dam or into other topographic depressions beyond the reservoir basin. The terminal structure prevents excessive erosion of the stream channel or damage to adjacent structures and the dam from the high-energy spillway discharges. Stilling basins, roller buckets, baffled impact-type basins, and lined aprons are used as terminal structures.

Spillway systems typically consist of a principal spillway and an auxiliary spillway (often referred to as an emergency spillway). The principal spillway is the first-used spillway during base inflow and flood flows. The auxiliary spillway is a secondary spillway designed to operate in conjunction with the principal spillway; when used, the principal spillway aims to pass floods that occur often, and the auxiliary spillway is set to operate only after such small floods are exceeded. The combination of the principal and auxiliary spillway should safely pass the design flood without overtopping the unprotected part of the embankment.

The following types of spillways (as shown in Figure 6-1) are used at dams; however, many variations of these spillways are found in practice:

- Drop Inlet Spillway (also called Morning Glory Spillway, or Shaft Spillway) – A vertical or inclined shaft into which flood water spills and then is conducted through, under, or around a dam by a

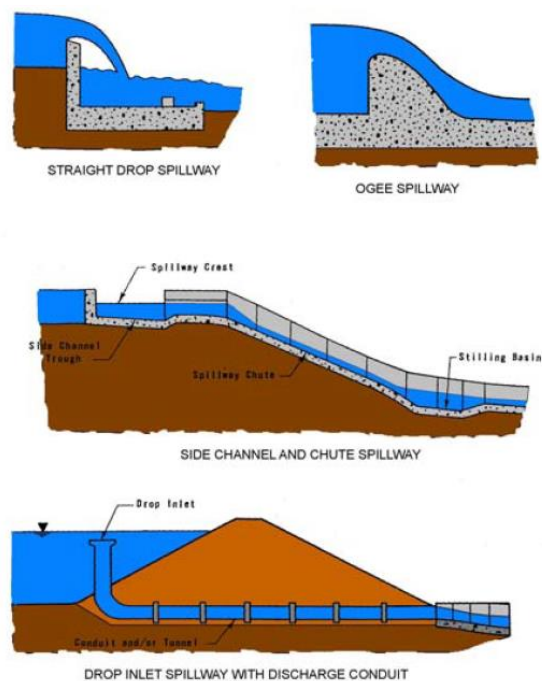


Figure 6-1. An illustration of several types of spillways used in India. Many variations of these spillway types will be found in practice.

conduit or tunnel. If the upper part of the shaft is splayed out and ends in a circular horizontal weir, it is termed a “bell-mouth” or “morning glory” spillway. The vertical part of the spillway is called the riser. The risers are usually reinforced concrete pipes or boxes. Shaft spillways are often used as the principal spillway and are usually referred to as drop inlets or risers.

- Side-Channel Spillway – A spillway formed on the natural ground along the side of an embankment. Auxiliary spillways are usually side-channels. However, principal spillways may also be side channel spillways. Side-channel spillways may be constructed with energy dissipation structures, such as baffles or stilling basins, to reduce discharge velocity and energy.
- Conduit Spillway – A spillway consisting of a closed channel, or conduit, that conveys the reservoir discharge under or through the dam embankment. The closed channel may be a vertical, horizontal, or inclined shaft and may be used

in conjunction with most forms of control sections, including overflow crests, drop inlet entrances, and side channel crests. Conduit spillways are sometimes used without another type of control structure.

- Ogee Spillway – An overflow weir in which the cross section of the crest, downstream slope and bucket have an “S” (or ogee) form of a curve. The shape is designed so that the underside of the nappe matches the upper extremities of the weir.

Spillways are critical to the safe operation of every dam and must be inspected closely. Many problems that occur at spillways may not be visible until damage or failure occurs. This is particularly true with problems that develop along or under conduits in embankments, or under concrete linings (FEMA 2005b). The riser on a shaft spillway is usually submerged in the reservoir, making it difficult if not impossible to examine all parts of the spillway. Boat access may be needed on some, while professional scuba divers may be required to inspect others. For this reason, inspectors must be alert for any signs of deterioration or damage that may be present, but may not be visible during a surface inspection.

Seepage, or filter, diaphragms are newer technology and have replaced the anti-seep collars as the preferred method of seepage control. A diaphragm is an engineered filter placed near the downstream end of the conduit that prevents seepage water from removing the soil from around or under the conduit. Filter diaphragms are connected to a horizontal granular layer or pipe drain to convey seepage from the diaphragm away from the embankment. Anti-seep collars may contribute to piping problems, and the embankment should be closely inspected for problems if they are used.

The outlet is the structure through which water can be freely discharged from a reservoir. Outlets are used to reduce the reservoir level in dams or to maintain a desired flow downstream of the dam. An outlet may also

be referred to as a reservoir drain. The primary function of the outlet (also called outlet works, or outlet system) is to control the release of water from the reservoir. The outlet system is used to release water downstream for irrigation, dam repairs, emergencies, and other uses. The size of the outlet system is set by the rate of demand downstream or the desired rate of drawdown that may be needed for maintenance. Except in an emergency, the rate of drawdown of the reservoir should be slow; not exceeding one foot per 24-hour period is typical. In an emergency, drawdown should be carried out as quickly as possible without creating excessive hazards at the dam, its appurtenances, or the area downstream.

The outlet works components may include the following: entrance channel, intake structure, waterway or conduit, a control section, terminal structure, access shafts, bridges, and tunnels, and operation/ maintenance stations.

The entrance channel (if present) conveys water to the intake structure of the outlet works. The intake structure establishes the ultimate drawdown level, guards against the entry of trash, and may incorporate water control devices (valves) for flow regulation, or closure devices for dewatering the outlet works during visual inspection and maintenance. 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 capacity for siltation, the required amount and rate of withdrawal, and the desired maximum drawdown level.

The waterway conveys the released water from the intake structure to the point of downstream release. Waterways may be steel-lined sluiceways or ports through concrete dams, lined or unlined tunnels in abutments, or from the reservoir basin elsewhere, open channels, or closed conduits beneath the dam. Closed waterways may be designed for pressure and non-pressure flow. Pressure pipelines and penstocks may be extended through non-pressure conduits and tunnels, affording access and pressure relief.

The control section regulates the flow of water through the outlet works and may be located at the upstream or downstream limits of the waterway, at intermediate positions, or at several positions. It houses and supports control devices that proportion or shut off outflow. Types of valves and gates used for control devices include slide gates; commercial gate valves; butterfly valves; ring follower, fixed-wheel, and roller train leaf gates; needle, tube, jet flow, hollow-jet, and Howell-Bunger valves; and bottom seal and top-seal radial gates. For satisfactory performance, the type of valve or gate must be matched to service conditions such as the largest pressure, flow velocity, in line or free discharge, fully open, closed, or partially open, and unbalanced or balanced head operation.

The terminal structure delivers the flows to the point of downstream release. The need for and the type of terminal structure are defined by the purpose of the outlet works. The terminal structures can be separate structures similar in principle to those for spillways, or the outlet releases may be conveyed through the spillway discharge conduit and terminal structure.

Inspectors should visually inspect the outlet and all its components. Arrangements should be made with the dam owner to have someone operate the outlet; Inspectors should not operate the outlet to avoid potential liability issues involving the release of water, or possible breakage or sticking (in open position) of control valves.

6.2 Inspection Procedure

Spillways and outlets may be difficult to access, so the best approach is to walk closely along or in the structure, depending on access, and view all surface and internal areas, if possible. If conduits are large enough and appear safe, inspectors should be able to walk into the structure with a flashlight and view the inside areas. If the structure is in the water away from the shoreline or embankment, an inspector may need to use a pair of binoculars or a camera/video camera with a telephoto lens. Pictures or videos can be taken

and reviewed carefully from a safe location. Boats or underwater divers may need to be used to see some features. Shorelines and upstream areas may be accessed on foot or by vehicle. Other appurtenant works should be closely inspected, item-by-item, from as close a distance as possible. Gates may need to be closed to make the inspection possible. Some structures may not be readily accessible and will require binoculars or video equipment to observe current conditions.

6.3 What to Look For

There are four general types of problems that can prevent a spillway or outfall from functioning properly: (1) cracks and structural damage; (2) inadequate erosion protection; (3) deterioration or lack of maintenance; and (4) obstructions. As soon as any of these problems is found, remedial steps should be taken to correct the defect. Each of these types of problems is described in detail in this chapter. Additionally, special concerns of conduits and outlets are discussed separately, including visual inspection guidelines and testing procedures.

The spillway is an important part of a dam. If it has not been designed with adequate capacity, or is not constructed and maintained properly, overtopping of the embankment may occur during a large storm. This could cause failure of the dam or its components and severe damage to downstream properties, or even death of downstream residents. A spillway should always be kept free of obstructions, be able to resist erosion and be protected from deterioration. An inspector must visually examine spillways and outlets for potential deficiencies to ensure the continued safety of the dam.

In general, spillways are either open channels or conduits. Open channel spillways are easier to inspect because they are typically easier to access. Steep sidewalls or flowing water in open spillways may make visual inspection dangerous for an inspector. Many dams in India use pipes (or conduits) that serve as principal spillways or outlet structures. Pipes placed through embankments may be difficult to construct properly,

can be extremely dangerous to the embankment if problems develop after construction, and are usually difficult to inspect and repair because of their location. Great attention should be directed to visually inspecting and maintaining these structures.

Frequent visual inspection of the spillway and outlet conduits is necessary to ensure that they are functioning properly. All conduits should be inspected thoroughly once a year as part of the scheduled inspection program. Conduits which are 75 centimeters or more in diameter can be entered and visually inspected with proper precautions and equipment. The conduits should be inspected for improper alignment (sagging), elongation, separation, displacement at joints, deformation, undermining, cracks, leaks, surface wear, loss of protective coatings, corrosion, and blockage. Problems with conduits occur most often at joints. Therefore special attention should be given to the joints during the visual inspection. The joints should be checked for gaps caused by elongation or settlement and loss of joint filler material. Open joints can lead to erosion of embankment material or cause leakage of water into the embankment during pressure flow. The outlet should be checked for signs of water seeping along the exterior surface of the pipe. Depressions in the ground surface above the conduit may be a sign that soil is being removed by internal erosion.

An inspector must be careful when entering closed conduits. These areas are potentially confined spaces and may hold noxious gasses, or may lack enough oxygen. If in doubt, inspectors should use a portable gas meter to check the air in a conduit before entering. Conduits also present potential hazards to an inspector's physical safety.

Inspectors should look carefully for signs of structural damage to spillways and outlets that could create a safety hazard. Structural damage usually results from foundation problems or settlement of fill material around or under the structure. Cracking and displacement of the structure are typical outward signs of structural damage.

Outlets (drains or drawdown structures) should be operated every time formal technical or scheduled inspections are performed. In addition, they should be operated at least twice annually and especially just before the annual flood season, typically March in India. This will help keep the equipment in working order and verify its performance. Unused outfall valves and controls can become corroded or blocked with sediment, so routine testing can help keep these devices working properly. Precaution must be exercised to prevent downstream flooding by releasing too much water. Dam owners are responsible for operating the outlet structures during an inspection; inspectors should not take on this task.

A visual inspection of the outlet may require advance planning to allow outflows to be shut off and inundated areas to be pumped out. Inspection by the owner or his representative can usually discover complications with the outlet. In most cases, a qualified dam safety professional will be needed to recommend corrective action when problems are found.

The rest of this chapter focuses on the visual inspection and identification of specific problems that may be found on spillways and outlets. The information is presented by the type of deterioration (i.e., cracks and structural damage, inadequate erosion protection, deterioration, and obstructions) for the several types of spillways and outlets that are usually found.

6.4 Cracks and Structural Damage

Minor cracking is sometimes present on concrete-lined spillways, concrete pipes, and conduits. Significant cracking, however, often causes (or is the result of) vertical and/or horizontal displacement, and misalignment of the structure. Structural damage may affect any type of spillway or outlet structure and is usually caused by foundation problems in the soil or rock below the structure in question. Cracks may also be considered as deterioration, but they are discussed separately be-

cause of their importance to structure stability. Concrete structures are often undermined by water seepage or piping, and eventually, experience structural damage as the concrete settles into the underlying voids.

6.4.1 Concrete Spillways and Outlets

Cracks are defects that are often found on concrete spillways; they are less common in outlets, although they still occur there. Cracks may be caused by foundation problems, water pressure, concrete expansion, freeze-thaw effects, poor concrete mix design, poor construction practices, and chemical reactions. The discussion of cracks in this section applies to both spillways and outlets.

By definition, a crack is a separation of portions of a concrete structure into one or more major parts and is usually the first sign of concrete distress. As described in Chapter 5, there are two broad categories of cracking found in concrete structures: (1) individual cracks, and (2) pervasive cracks. When spillway concrete exhibits pervasive cracking and has extensively cracked surfaces, the primary focus of the visual inspection should be the location, nature, and extent of cracking rather than the dimensions of individual cracks. If individual cracking is spotted, the location and dimensions should be recorded for each crack and whether they are structural or surface cracks. ACI standardized terms to describe the appearance of individual cracks includes direction, width, and depth and are listed in Table 5-1. ACI Standardized Terminology for Individual Concrete Cracks (ACI 2008)

Cracks in the concrete may be structural or surface cracks. Surface cracks are less than a 2-mm wide and less than 2 mm deep. These are often called hairline cracks and may consist of single, thin cracks, or cracks in a craze/map-like pattern. A small number of surface or shrinkage cracks is common and does not usually cause any problems. Surface cracks are caused by freezing and thawing, poor design or construction practices, and alkali-aggregate reactivity. Large cracks present the greatest potential for safety concerns and

usually develop because of structural problems. Large cracks will usually result in rapid deterioration of the spillway. Misalignment and displacement of spillway walls and chute slabs are often associated with large cracks. These cracks may be caused by uneven foundation settlement, foundation erosion, slab displacement, or excessive earth or water pressure. Large cracks will allow water to wash out the materials below or behind the concrete slab, causing erosion and leading to more cracks. Extensive cracking can cause the concrete slab to be severely displaced, dislodged, or washed away by the flow. When large cracks are found, inspectors should look for structure alignment and foundation problems.

Cracks create openings in the concrete that permit further deterioration of the concrete. A concrete spillway may have to withstand considerable hydrostatic pressure from the reservoir and groundwater. Hydrostatic pressure acting along cracks through the concrete structure may exert dangerous uplift forces, leading to lateral propagation of the cracks and uplifting, settlement, or sliding of a part of the structure. A severely cracked concrete spillway should be examined by a qualified dam safety professional.

A crack in a concrete conduit through an embankment dam could allow reservoir water under pressure to enter and erode the embankment along the conduit. Cracks that cause leakage into the embankment or into the pipe from the reservoir should be repaired at once. These cracks are usually structural cracks in the conduit walls and floor, caused by uneven settlement or foundation erosion.

Large cracks may be a sign of structural problems and are potential safety concerns. The location, width, length, and orientation of the crack(s) should be recorded during the visual inspection. Large cracks are often the result of serious problems under the concrete. Inspectors should also decide if concrete around the crack has deteriorated or whether reinforcing bars are exposed.

Spillway retaining walls or chute slabs may be displaced from their original position because of foundation settlement, or earth or water pressure. An inspector can sight carefully at the upstream or downstream end of the spillway near the wall to decide if it has been tipped inward or outward. Relative displacement or offset between adjacent sections of concrete can be readily detected at the joint. The horizontal and vertical displacement should be measured and recorded. If a fence line was constructed on top of the retaining wall, it could be used to help decide if the wall is distorted. Fences are usually erected in a straight line at the time of construction. Therefore, a curve or distortion of the fence line may show that the wall has deformed.

The entire spillway chute should form a smooth surface. Measurement of relative movement between neighboring chute slabs at the joint will give a good sign of the slab displacement. Large cracks and associated problems are usually easy to see during a visual inspection. A clear description of crack patterns should be recorded and photographed to help understand the cause of the displacement.

A large crack is often a structural crack and may demand immediate repair. A large crack in a concrete spillway or discharge channel also could allow the erosion of underlying material, resulting in loss of support and failure of the spillway. A badly cracked channel wall might fall when subjected to pressure from a large discharge. Inspectors should always closely evaluate large cracks and assess their potential impact on the safety of the dam.

6.4.2 Earthen Spillways

Earthen spillways may be affected by the same type of cracking problems found on embankments (see Chapter 4.). However, cracks observed in earthen spillways are usually not as critical as those on embankments because the spillways are typically on in situ ground. Desiccation cracks in an earthen spillway or channel are usually not regarded as a functional problem but should be noted

on the inspection report nonetheless. Deep cracks that are wider than 1 cm may be signs of slope stability issues, including sloughing or sliding.

The side walls of earthen spillways are usually more vulnerable to stability problems than the floor because they are steeper and may contain groundwater seeps. Seepage from the reservoir or in situ ground may saturate spillway soils, making conditions for a slide favorable. Cracks that are deep and wide (greater than 1 cm) may be an indication that a slide is developing in the soil. Cracking should be considered as a serious problem if it is the beginning of a slide. Slides are structural problems that can reduce the spillway capacity by obstructing the flow path, or can lower the elevation of the spillway control section, depending on the location of the slide. Inspectors should monitor the condition frequently for sloughing, bulging, or the formation of scarps.

If cracking or slides are observed during a visual inspection of an earthen spillway, the following actions should be taken:

- Photograph and record location, depth, length, width, and offset of the cracks or scarps, if present.
- Make sure that the spillway control section and discharge channel are on in situ ground. If not, note this as a serious concern.
- Look for any surrounding cracks.
- If a bulge is present, closely inspect the area above the bulge for cracking or scarps which might indicate that sliding is a cause. Probe the bulge to determine if the material is excessively moist or soft. Excessive moisture or softness usually shows that sliding is a cause.
- Look for evidence of seepage or saturated soils in or below the cracks or slide. Probe the entire area to determine the condition of the surface material.
- Determine if other dam structures, such as the embankment, could be affected by the cracking or slide in the spillway.

- Closely monitor the cracks or slide for changes.
- Consult a qualified dam safety professional to determine the cause of the cracking or slide if it is severe or gets progressively worse. Serious cracking, slides or repair operations may require lowering the reservoir level. In most instances, deep-seated slides near or at the control section will require the lowering or draining of the impoundment to prevent the possible breaching of the dam.
- Recommend appropriate corrective action be taken to repair or to replace the damaged spillway areas.

Inspectors should consider the worst-case scenario when evaluating earthen spillways. This typically means a condition in which the spillway is flowing at maximum design levels. The frequency, duration, depth and velocities of potential spillway flows need to be taken into account.

6.5 Inadequate Erosion Protection

When a large storm occurs, the spillway system is expected to carry a significant amount of water for many hours. Severe erosion damage or complete wash-out could result if the spillway lacks the ability to resist erosion. If the spillway is excavated in a hard rock formation or lined with concrete, erosion is usually not a problem. But, if the spillway is excavated in sandy soil, deteriorated rock, clay, or silt deposits, then erosion protection is critical. Resistance to erosion can be increased if the spillway channel has a mild slope, or if it is covered with a layer of grass or riprap with bedding material.

Erosion at a spillway outlet, whether it be a pipe or overflow spillway, is one of the most common erosion problems encountered. Severe erosion or undermining of the outlet can displace sections of pipe, cause slides in the downstream slope of the dam as erosion continues, and eventually lead to complete failure of the spillway or dam. Water must be conveyed safely from the reser-

voir to a point downstream of the dam without endangering the spillway or embankment. Often the spillway outlet is adequately protected for normal flow conditions, but not for extreme discharges. It is easy to underestimate the energy and force of flowing water and/or overestimate the resistance of the outlet material, such as earth, rock, or concrete. The required level of protection is hard to establish by visual inspection, but can usually be determined by hydraulic calculations performed by a professional engineer. Missing rocks in a riprap lining can be considered as a breach in the protective cover, and this should be repaired as soon as possible. Inspectors should look for signs of erosion and inadequate erosion protection at the outlet of all spillways and outlets.

Stilling basins are often used at outlets to absorb the discharge energy and consist of a lined depression at the outlet of the spillway or outlet conduit. Stilling basins are usually lined with loose rock riprap and a suitable bedding/filter material (Figure 6-2). Displaced riprap placed inside stilling basins can result in more scouring in the pool which creates a deeper or larger depression and sedimentation downstream. If the scouring is severe, it can erode the toe of embankment dams, or undermine the outlet of spillways and outlets. Inspectors should look for signs of rock displacement and scour, especially in the downstream end of the basin, and sedimentation in the receiving channel.

Vegetative lining (grass) is often used in auxiliary spillway discharge channels. Grass linings can protect soil on flat slopes and low discharge velocities. Typically, grass linings are adequate for water velocities of 1.5 m/s or less. Bare spots, or areas where the grass is sparse, are susceptible to erosion problems and should be carefully inspected for erosion rills and gullies. Wide grass-lined spillways should be examined for erosion gullies and rills from stormwater runoff within the spillway.

The runoff from rainfall will often concentrate in specific areas in the spillway and erode the surface soils. Although this is usu-

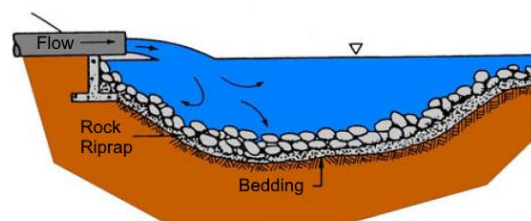


Figure 6-2. Illustration of a typical stilling basin lined with rock riprap at a spillway outlet.

ally not a problem, it should be corrected before the erosion gullies get too deep. Shallow erosion rills should be monitored for additional damage from rainfall. Erosion rills and gullies become worse with time. Inspectors should determine the cause of the formation of the erosion features and recommend repairs that correct this problem. Often it is the result of uneven grading practices that tend to make the runoff flow to one spot or route in the spillway.

Many new synthetic lining materials are also available that will protect soil spillways from erosion at much higher velocities than grass. The degree of protection offered by these linings varies with the manufacturer and type of material. These materials are installed as blankets and should be inspected for undermining, tearing, displacement, and exposure to the sun.

Reservoir outlet works usually discharge into the spillway terminal structures, and the discharge from these structures may be intermittent. When the outlets include a separate outfall point and terminal structure, they should also be examined in the same manner as the spillway structures.

During the visual inspection, inspectors should look for inadequate erosion protection:

- Make sure that the grass, riprap, or other erosion protection is adequate to prevent erosion. Bald areas or areas where the surface protection is sparse are more susceptible to surface runoff and flowing water problems.
- Look for gullies, ruts, or other signs of surface runoff erosion. Be sure to check

the low points at the spillway outfall, and areas where stormwater runoff can concentrate.

- Check for any unique problems, such as livestock or recreational vehicles that may be contributing to erosion.

If the spillway protection is found to be inadequate, inspectors should:

- Record the findings and photograph the area.
- Determine the cause and extent to which the spillway has been damaged (i.e., spillway foundation or soil material has been removed).
- Recommend that corrective action is taken to repair or to replace the inadequate spillway protection.
- Consult a qualified dam safety professional if necessary.

If erosion is discovered, inspectors should:

- Record their findings and photograph the area.
- Determine the extent, severity, and cause of the damage.
- Recommend that corrective action is taken to repair the areas damaged by surface runoff and that measures are taken to prevent more serious problems.
- If spillway control sections need to be repaired, or extensive embankment excavation is required, the reservoir level may need to be lowered.

6.6 Deterioration

Deterioration is any adverse change on the surface or in the body of spillways and outlets that cause the structure to separate, break apart, or lose strength. The term, deterioration, is most used in reference to the general condition of a construction material such as concrete, rock, metal, plastic, or wood and can result in the complete destruction of material. The amount of deterioration which has occurred in a material is evaluated with respect to its original condition.

Deterioration of material is normally caused by the forces of nature such as wetting

and drying, freezing and thawing, oxidation, decay, ultraviolet light, and erosive forces of wind and water. Activities of humans can also contribute to deterioration by altering the chemical composition of water through the application of chemicals on or near a dam. A subjective evaluation of the extent and effects of deterioration should be made. Sometimes deterioration will be extensive enough to result in other detrimental conditions. These include riprap deterioration because of bedding erosion, structural failures of concrete because of reinforcing corrosion, erosion, and piping caused by metal pipe corrosion, and plastic pipe cracking from ultraviolet light deterioration.

Outward signs of deterioration include conditions such as the collapse of side slopes, weathering of material, the disintegration of riprap, the breakdown of concrete lining, erosion of the concrete spillways, sloughing of discharge channels, excessive siltation of a stilling basin or discharge channel, and loss of protective grass cover. These conditions can lead to flows under and around the protective material which can cause severe erosion. Remedial actions should be taken as soon as any sign of deterioration has been detected, even during storm flows. Cracks are a form of deterioration; cracking was discussed in detail earlier.

Inspectors should try to understand as fully as possible why deterioration has occurred. Understanding the cause may reveal a solution or measures that would prevent further damage. A large concrete spall next to a joint, especially on a spillway slab, will require careful examination of the joint. As an example, loss of joint filler and replacement with sand or sediment can make joints too rigid to expand, causing spalling. Cleaning debris from joints and application of new joint filler might prevent further spalling.

6.6.1 Concrete Structures

Most concrete structures in India experience some form of deterioration from the severe nature of the climate and the dam environment. Most forms of concrete deterioration develop over an extended period of time with

visual warning signs. So, there is usually sufficient time to repair the structure before total failure occurs.

Deterioration of concrete may be caused by many factors, including weathering, mechanical impacts, internal pressure, drying shrinkage, thermal stress, chemical action, leaching by water seepage, poor concrete mixes, poor concrete design, and freeze-thaw action. The use of excessive mix water is the single most common cause of damage to concrete. It may be difficult to isolate the specific cause of concrete deterioration. If inspectors are not sure, they should obtain professional help, or define the potential cause within a range of two or three plausible causes. Sometimes, more than one mechanism may be involved. For example, cracking from thermal stress or drying shrinkage may lead to freeze-thaw action or leaching by water seepage.

Deterioration can weaken the design strength of a concrete structure and cause it to fail. Concrete deterioration may cause leakage and associated water pressures to increase. Deterioration may also result in distortion of a structure, causing binding of mechanical features such as gates which must operate to ensure the safety of a dam. Inspectors should look for damage to other equipment and structures because of the concrete deterioration.

Deterioration may be isolated to some concrete elements or may be caused by a serious flaw in all the concrete used in a structure. When stresses such as hydrostatic pressure or earth loads exceed the strength of a weakened element or structure, the dam or appurtenances may fail catastrophically. Some forms of deterioration may soon be affecting the safety of the structure. Seepage through a weakened concrete structure is a genuine problem and needs immediate attention. Inspectors should examine all concrete surfaces for seepage, and record any findings.

If a poor concrete mix is a cause of deterioration, inspectors should examine construction records for information about the

concrete. Poor concrete mix design involves larger areas of the structure.

Often, concrete that is cast around corrugated spillway conduits creates problems caused by differential expansion and contraction. The two dissimilar materials expand and contract at different rates which may result in cracks in the concrete. Another problem created by casting concrete around corrugated pipes is the potential lack of adhesion between the concrete and pipe surfaces, resulting in seepage along the pipe. Inspectors should carefully examine areas where pipes and conduits are connected to other structures for signs of deterioration and seepage.

An inspector also should look for failure of repairs. Corrective action for concrete deterioration often includes removal of the deteriorated concrete and replacement with superior concrete or another repair material. Shallow repairs with epoxy materials may fail with large drops in air temperatures. Patched areas tend to shrink and crumble, and often the patch material does not adhere well to the original surface.

An inspector can use the following terms to describe concrete deterioration. Many of the terms are interrelated, with one type of deterioration producing one or more other types. The use of common terminology will help reviewers to understand the defects and problems better. ACI 116, *Cement and Concrete Terminology*, is a reliable source of information to use to describe concrete deterioration.

Disintegration

Disintegration is the crumbling or deterioration of concrete into small particles which could cause failure of a concrete element or structure. Disintegration is one of the most serious forms of concrete deterioration that can be a result of many causes such as freezing and thawing, chemical attack, and poor construction practices.

All exposed concrete is subject to freeze-thaw, but the concrete's resistance to weathering is determined by the concrete mix and the age of the concrete. Concrete with the proper amounts of air, water, and cement,

and a properly sized aggregate will be much more durable. In addition, proper drainage is essential in preventing freeze-thaw damage. When critically saturated concrete (when 90% of the pore space in the concrete is filled with water) is exposed to freezing temperatures, the water in the pore spaces within the concrete freezes and expands, damaging the concrete. Repeated cycles of freezing and thawing will result in surface scaling and can lead to the disintegration of the concrete. Hydraulic structures are especially susceptible to freeze-thaw damage because they are more likely to be critically saturated. Older structures (pre-1940) are also more susceptible to freeze-thaw damage because the concrete was not air-entrained. In addition, acidic substances in the surrounding soil and water can cause disintegration of the concrete surface because of a reaction between the acid and the hydrated cement. Inspectors should record visible signs of deterioration and try to determine the cause while at the site.

Large areas of crumbling (rotten) concrete, areas of deterioration which are more than about 7 to 10 centimeters deep (depending on the wall/slab thickness), and exposed rebar are signs of severe concrete degradation. If not repaired, this type of concrete deterioration may lead to structural instability of the concrete structure. A registered professional engineer should prepare plans and specifications for repair of serious concrete damage.

Scaling

Scaling is the flaking or peeling away of the concrete or mortar surface. Scaling also results in susceptibility to further deterioration of the structure. Scaling is a milder form of disintegration.

Spalling

Spalling is the loss of larger pieces of concrete (usually flakes or wedge-shaped pieces) from a surface, often at edges, caused by a sudden impact, external pressure, weathering, internal pressure (e.g., corroded rebar near the surface), expansion within the concrete mass, or fires built on or against structures. It often occurs in concrete on exposed

surfaces at corners or at joints. Concrete spalling could be the result freeze-thaw action, a repair which has deteriorated or stresses on a concrete structure which exceeds the design. In spillways or outlets, it may be caused by the impact of rocks or other debris against the flow surface. Joint spalling is usually caused by erosion, weathering, and ice damage but can also be caused by structure movement. Other causes include reinforcing deterioration, chemical reactivity of aggregates, and vandalism. When found, the structure should be checked for other degradation, displacements, and structural damage.

Spalling usually affects only the surface of the structure, so it is not ordinarily considered dangerous. However, if allowed to continue, spalling will cause structural damage, particularly if the structure has a thin cross section. Spalling often results in exposed reinforcing; leakage paths opened around embedded waterstops at joints; offsets on flow surfaces; and development of points of structural weakness. Repair is necessary when reinforcing becomes exposed to the elements. The method of repair of areas where spalling is taking place depends upon the depth of the deterioration. Repair should be considered temporary unless seepage through the structure can be halted. However, if a fragmented piece of concrete is large and causes structural damage, a registered professional engineer should prepare plans and specifications to repair the damaged area.

Popouts

Popouts are a form of small-scale spalling, and occur when a small part of the concrete surface breaks away because of internal pressure. Popouts are usually formed as the water in saturated coarse aggregate particles near the surface freezes, expands, and pushes off the top of the aggregate and surrounding mortar to create a shallow conical depression. Popouts are typically not a structural problem, but they do make the structure susceptible to further deterioration.

Pitting

Pitting is the development of small cavities in the concrete surface caused by localized disintegration. Once pitting begins it usually continues to worsen. There are several causes of pitting including weathering (freeze-thaw cycles), mechanical damage, and local chemical attack.

Efflorescence

Efflorescence is the leaching of calcium compounds from within the concrete and deposition on the surface because of water leaking through joints, cracks, or the concrete itself. It appears as a white, crystallized substance on the concrete surface. The seepage water dissolves soluble calcium hydroxide from cement within the concrete and carries it to the exposed face of the concrete. As water evaporates from the concrete surface, calcium hydroxide is deposited. These deposits react with carbon dioxide in the air to form calcium carbonate or the hard, white deposits normally observed. The problem with water seepage is that as calcium hydroxide is leached from the concrete around the joint or crack, the opening widens allowing increased seepage. Widening of joints and increased seepage can lead to increased rates of deterioration and eventual loss of concrete strength.

By itself, efflorescence is not a problem except for the obvious undesirable effect on the concrete appearance. The amount of efflorescence and any increases in this amount over time should be visually evaluated to determine the potential for seepage to affect the integrity of the particular concrete structure.

Efflorescence is usually located near hairline cracks or thin cracks on spillway sidewalls. Efflorescence is usually accompanied by seepage. The seepage can make the concrete more susceptible to freeze-thaw action. In some cases, openings may be sealed against additional leakage by deposits. The deposits may even stop up drain holes and other leakage control features. Efflorescence should be monitored because it can indicate the amount of seepage finding its way through thin cracks in the concrete and can

signal areas where problems could develop, such as inadequate drainage behind the concrete or concrete deterioration.

Drummy concrete

Drummy concrete is concrete with a void, separation, or other weakness beneath the surface, detected by a hollow sound when struck with a hammer, bonker, or another steel tool. Drummy concrete may result in diminished strength of concrete and susceptibility to further deterioration.

Faulty concrete mixes usually result from improperly graded aggregates, improper cement to water ratio, lack of or improper percent of entrained air, inadequate mixing, placing, or curing procedures or equipment, or improper use of additives. A faulty concrete may have a lack of strength or may be susceptible to deterioration.

Chemical sulfate attack

Chemical sulfate attack is a reaction between sulfates (calcium aluminate compounds) in soil and groundwater with concrete. This type of deterioration may be caused using pre-1930 mix designs that did not consider sulfate attack. The presence of sulfates in local soil or ground water may also be the cause. Sulfate may be derived from natural sources, manufacturing plant wastes, or agricultural runoff contaminating the reservoir water. The concrete usually appears light in color and falls apart easily when struck with a hammer. Other signs of chemical sulfate attack include cracking, spalling, scaling, stains, or total disintegration of the structure or portions of the structure. Type V Portland cement is highly resistant to sulfate attack.

Chemical acid attack

A chemical acid attack is caused by the action of acidic water on calcium hydroxide found in hydrated Portland cement, limestone, or dolomitic aggregates. Acidic water in the reservoir may originate from sewage discharges, coal mine drainage, cinder storage piles, atmospheric gasses from nearby industry, industrial wastes, or severe acid rain. A chemical acid attack often leaches away acid-

soluble compounds in the concrete, potentially resulting in complete removal of the concrete surface or a color change of the structure surface. Corrosion and weakening of the reinforcing may also occur, resulting in overstressing of adjacent concrete, which may crack or spall.

Alkali-aggregate reaction results from a chemical reaction between soluble alkali present in cement and certain forms of silica present in some aggregates. The use of marine sediments as aggregates or shale from river gravels composed of cherts often causes alkali-aggregate reactions. This chemical reaction produces byproducts in the form of silica gels which cause expansion and loss of strength within the concrete. Alkali reaction is characterized by certain observable conditions, such as cracking, usually of the random pattern on a large scale, and by excessive internal and overall expansion. Additional indications are a gelatinous exudation and whitish amorphous deposit on the surface, and lifeless, chalky appearance of the freshly fractured concrete. The reaction takes place in the presence of water. Surfaces exposed to the elements or dampened because of dam seepage will show the most rapid deterioration. Once suspected, the condition can be confirmed by a series of tests performed on cores drilled from the dam.

Although the process of deterioration is gradual, an alkali-aggregate reaction cannot be economically corrected by any means now known. Continued deterioration often requires total replacement of the structure. Deterioration of concrete from alkali-aggregate reaction may cause abnormal expansion and cracking that may continue for many years. Low alkali portland cement and fly ash pozzolan can be used in new concrete to eliminate or reduce the deterioration of reactive aggregates.

Metal corrosion

Metal corrosion is the formation of iron oxide, or rust when water (especially salt water) reaches steel in the concrete. It may also be corrosion of aluminum if used when water reaches aluminum embedded in or on the

concrete. It is often caused using deicing salts on bridge decks and similar structures that can cause corrosion without initial deterioration of concrete. Corrosion typically results in an increase in the volume of the reinforcing metal that causes cracking and spalling of overlying concrete (mostly affecting thin structures). Typically, the bond is broken between the steel (or aluminum) and concrete, destroying the structural strength. Visible signs of metal corrosion include straight, uniform crack lines above reinforcing, rust stains on the surface, spalling, exposed reinforcing, and deterioration of concrete next to unprotected aluminum fish ladders, hydraulic pumps, gates, and guard rails.

Concrete erosion

Erosion of concrete is caused by fast-moving water carrying abrasive material such as sand and gravel, debris, and ice. Ballmilling is a form of erosion which is the grinding away of a surface, usually in a circular pattern, especially within stilling basins. Erosion results in the wearing of softer aggregates, or of the matrix material around the aggregates. Inspectors should also look for abrasion erosion at points of abrupt change in flow channels or at corners, and the loss of concrete from the surface. Erosion in its worst form may result in the severe destruction of concrete.

Erosion from abrasion results in a worn concrete surface, with polished-looking aggregate. It is caused by the rubbing and grinding of sand and gravel or other debris on the concrete surface of a spillway channel, conduit, or stilling basin. Minor erosion is not a problem, but severe erosion can jeopardize the structural integrity of the concrete.

Erosion caused by cavitation results in a rough pitted concrete surface. Cavitation is a process in which subatmospheric pressures, turbulent flow, and impact energy are created and will damage the concrete. If the shape of the upper curve on the ogee spillway is not close to its ideal shape, cavitation may occur just below the upper curve, causing erosion. If the concrete becomes severely pitted, it

could lead to structural damage or failure of the structure.

Joint Deterioration

Spillway retaining walls and chute slabs are normally constructed in sections. Between adjoining sections, gaps or joints must be tightly sealed with flexible materials such as tar, epoxies, or other chemical compounds. Sometimes rubber or plastic diaphragms or copper foil is used to seal the joint watertight. During the visual inspection, note the location, length, and depth of any missing sealant. Also, probe the open gap to see if soil behind the wall or below the slab has been removed by the erosive action of water.

Cavitation

Cavitation, a form of erosion, is the result of the formation of excessive negative air pressures in hydraulic structures. This condition is often caused by offsets or irregularities that produce turbulence. The results are usually pitting and spalling of the flow surfaces. Cavitation may be difficult to identify because it may be similar to other types of deterioration such as abrasion or corrosion of concrete, rock, and metal surfaces. Cavitation is not normally a problem where hydraulic heads are less than 40 meters. If evidence of cavitation is discovered, the history of flooding is needed to determine what event may have caused the damage and to evaluate the potential for additional cavitation to occur. Severe cavitation can produce extreme vibrations and erosion which may lead to structural damage and failure. Air vents to flow passages are often used to prevent cavitation. The vents should be examined visually or by pouring water into them to ensure that they are not obstructed.

Cavitation typically occurs downstream of gates and valves, and on steep spillway chutes, tunnels, or conduits. Cavitation creates the potential danger of rapid failure of a spillway or outlet works, and that may result in failure of the dam during large floods.

Surface defects

Surface defects are other concrete deficiencies that may not be progressive in nature;

that is, they do not necessarily become more extensive with time. Surface defects are usually shallow and do not normally present an immediate threat to the structure. However, they may make the concrete more susceptible to more significant deterioration. Surface defects may include:

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

Concrete structures often show signs of some form of deterioration described above.

Spillway entrance floors and walls may display a loss of lining, scour, and undermining of the structure. The spillway control section floor may suffer from broken slabs, undermining of the structure and exposing the foundation, cracking and spalling, exposed reinforcing, pitting, and scour. Typical causes of these problems include initial construction with poor concrete, high erosive forces, and unbalanced hydraulic pressure against the slab.

The control section pier, walls, and overflow crest may show signs of cracks, spalls, pits, scour, exposed aggregate, and exposed reinforcing. These deficiencies are the result of poor concrete mixes, chemical attack, erosion, alkali-aggregate reaction, and cavitation.

The discharge channel may display rough patches, loss of concrete, foundation erosion, and exposed reinforcing. These conditions are caused by cavitation resulting from rough surfaces or irregularities, and erosion from carried debris. Foundation erosion is caused by seepage under the structure.

Common problems in the stilling basin and submerged roller bucket include scour holes more than 15 cm deep in the floor, loss of floor slabs, exposed and damaged reinforcing, and boulders in the basin. These problems are most often caused by inadequate hydraulic jump formation, and gravel or boulders that roll into the basin or bucket.

Non-submerged flip buckets may have visible scour holes (over 30 cm in diameter), blocks of broken concrete, and exposed reinforcing. The usual cause of these conditions includes heavy debris not swept out of the bucket during operation.

Chute blocks or baffle blocks may develop damaged or displaced blocks, and exposed reinforcing caused by cavitation or large rocks or other hard debris in the basin or bucket.

The concrete outlet works usually consist of conduits. These structures may suffer from pattern cracking, pitting, and spalling. The most common cause of this damage is from chemical attack, erosion, cavitation, or deformation caused by high loads from earth embankments.

Reporting Concrete Deterioration

Condition surveys may be required to help evaluate concrete deterioration. Condition surveys are detailed engineering studies of concrete conditions that include reviews of engineering data, field investigation, and laboratory testing. If a condition survey was performed on a dam or its appurtenant structures, the survey should provide a basis for assessing the concrete deficiencies that may be encountered.

Surface mapping involves documenting concrete defects in a systematic manner. All types of concrete deterioration should be included. Surface mapping consists of developing a detailed record of the cracks on paper or on film so that future changes can be monitored. The mapping can be carried out using detailed drawings, photographs, or video to record the current features and deficiencies. When photographs are used, a ruler or familiar object should be included to give an idea of the scale. A grid is sometimes used to overlay a section of a drawing so the location of cracks and other defects can be shown easily.

If differential movement at joints or stress concentrations could have caused the damage, inspectors should review instrumentation or measurement data for evidence of these conditions, or recommend that more

instrumentation is installed to monitor the affected area.

If deterioration is found during a visual inspection of a concrete spillway or outlet, inspectors should take the following actions:

- Photograph and record location, type, and extent of the deterioration.
- Note prominent features, and whether cracking is also present.
- Look for structural damage, including misalignment, settlement, vertical and horizontal displacement.
- Look for any surrounding damage to structures or foundations.
- Classify and describe the deterioration using the terminology defined earlier.
- If deterioration is extensive, consider starting a condition survey or surface mapping to document all problems in the structure and their characteristics thoroughly. Contact a qualified dam safety professional if there is uncertainty about the severity of deterioration.
- Look for evidence of seepage or saturated soils in or below the structures. Also, look for signs of foundation soil erosion. If there is an excessive amount of water, or water which cannot be handled by the drainage system is flowing through a crack, recommend repairs. Check with a concrete specialist to choose the correct repair procedures.
- Determine if other dam structures, such as the embankment, could be affected by the deterioration in the spillway or outlet.
- Closely monitor the problems for changes.
- Try to find the cause of the deterioration; this can help plan effective corrective actions.
- Consult a qualified dam safety professional to determine the cause of the problem if it is severe or gets progressively worse. Serious deterioration or repair operations may require lowering of the reservoir level.

- Recommend corrective action be taken to repair or to replace the damaged spillway or outlet areas. The recommended corrective actions should be consistent with an inspector's training and experience.

6.6.2 Metal Structures and Materials

Metal structures serve several functions in dams and appurtenances. These structures may include metal gates and valves, conduits, cranes and hoists, and operating and access bridges. Some of these structures must always be operable to ensure the safety of a dam. Metal structures often serve as part of the outlet works that controls reservoir levels and releases excess flows, and so are especially crucial to dam safety. The failure of metal structures could form obstructions that would endanger a dam.

Corrugated metal pipes that are used as spillway structures can have serious problems besides corrosion. Usually, these problems are associated with installation practices and include foundation or backfill erosion, buckling, and crushing. These complications are usually caused by poor compaction of backfill material beside and over the pipe, and heavy equipment traffic over the pipe. Because of these problems, corrugated metal pipes are not recommended for initial placement, upgrades, or replacements in any dam.

Corrosion is an electrochemical reaction that results in the deterioration of metal by reaction with its environment. Metal suffers more damage from corrosion than from any other cause. Most metal deficiencies are types of corrosion, are related to corrosion, or eventually will involve corrosion. Coatings prevent or delay corrosion in metal. Therefore, failure of a coating may result in failure of the metal structure because of corrosion. Inspectors should be able to recognize the types and hazards of metal corrosion and distinguish hazardous metal corrosion from corrosion that is just a maintenance problem.

Destruction of metal parts obviously occurs by processes other than corrosion (e.g., abrasion, fatigue); however, these processes are often accompanied by corrosion of varying intensity. Corrosion may be widespread over the surface of a structure resulting in uniform loss of metal, or it may be highly localized, resulting in pitting of the surface and penetration of the metal. Either form may be destructive, depending upon the operating requirements of the structure.

Corrosion

Corrosion is a frequent problem of pipe spillways and other conduits made of metal. Exposure to moisture, acid conditions or salt will accelerate the corrosion process. Pipes made of non-corrosive materials such as concrete or plastic should be used in new dam construction, or in dam rehabilitation.

Corrosion of any metal part should be noted because it can weaken metal parts, decrease wall thicknesses, and hinder the operation of mechanical equipment. This identification should cover mechanical equipment, gates, valves, pipe spillways, lake drains, internal drain pipes, and other structural steel elements.

Frequently, corrosion is a significant problem with metal conduits, pipe and riser spillways, and drains. The type of pipe (smooth steel, corrugated metal, ductile iron), the protective coating or corrosion protection system and the wall thickness of the metal are factors that control the corrosion rate and severity. Seepage around a metal pipe at the outlet end may be an indicator of corrosion if joints are known to be watertight. Both water quality and soil conditions are other factors affecting the rate of metal corrosion. Metal conduits through embankment dams need to be examined with exceptional care for signs of corrosion. Corrosion holes and perforations could allow water into the surrounding embankment from the conduit, or into the conduit from the embankment. Either of these situations can result in piping through the embankment.

Corrosion of mechanical parts such as valve stems and guides could prevent operation of a drain or gate system in an emergency. A gate or valve broken during operation can also result in the unexpected draining of the impoundment and the danger of a sudden drawdown, which could trigger earth slides. Inspecting personnel should be alert and try to find the most probable cause of corrosion. Design errors, poor maintenance, severe weather conditions or a change in water quality could be contributing factors.

Corrosion may manifest itself in several diverse ways. Fontana (1987) describes eight different forms of corrosion as follows.

- 1) Uniform Attack – This is the most usual form of corrosion which progresses uniformly over a large area; resulting in uniform thinning of the surface and eventual failure if not controlled.
- 2) Galvanic or Bimetal Attack – Formed when different metals from the galvanic series are coupled. Corrosion is predictable according to the galvanic series.
- 3) Crevice Corrosion – Often intense and localized. May occur under gaskets, within lap joints, under surface deposits, mud, or other detritus.
- 4) Pitting Corrosion – Intense, highly localized corrosion resulting in holes of small diameter and large depth. May result in penetrations and leaks.
- 5) Intergranular Corrosion – Most often noted in or near improperly executed welds in stainless steels. May appear as “knife line” corrosion (as if the metal has been slit) or as thinning of the material in the heat-affected zone next to the weld.
- 6) Selective Leaching – The removal of one material from a solid alloy by corrosion. In cast iron, the removal of iron from the alloy, leaving only the carbon matrix (graphitization). In brasses, the removal of aluminum or zinc from the alloy (dealumification or dezincification). In either case, the remaining material has little strength.
- 7) Erosion Corrosion and Cavitation – This is deterioration of metals because of high-velocity impingement on the surface; resulting in directional pits and grooves.
- 8) Stress Corrosion – Often results in cracking of highly stressed materials (bolts, for example) in corrosive or mildly corrosive environments. Failure can be unanticipated and catastrophic. Stress corrosion cracking can also occur in improperly heat-treated metals. The failure of the part could be at a load that is much less than the intended design.

Common methods of protecting metals from corrosion include protective coatings (paint) and cathodic protection. A third method is used in the design process by incorporating, in the construction, materials that are immune from corrosion in the environment expected. Unfortunately, except for the occasional replacement of parts, this method is unavailable to the operator of an existing structure.

Metal pipes are available which have been coated to resist accelerated corrosion. Coatings can be of epoxy, aluminum, zinc (galvanized), polymers, or asbestos. Coatings applied to pipes in service are not effective because of the difficulty in setting up a bond. Bituminous coatings cannot be expected to last more than one or two years (in flowing water).

Corrosion of metal can also be controlled or arrested by installing cathodic protection (see Figure 6-3). A metallic, sacrificial anode such as magnesium, zinc, or aluminum is buried in the soil and is connected to the metal pipe by wire. Degradation of the anode produces an electrical current that flows from the magnesium (anode) to the pipe (cathode) and will cause the magnesium to corrode and not the pipe.

Another method of cathodic protection consists of the impressed current system, which includes a rectifier that converts an alternating power supply to a direct current that is properly calibrated to give the required

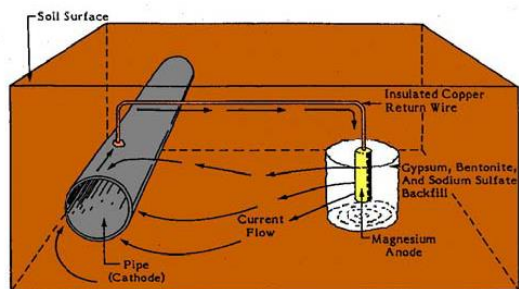


Figure 6-3. Illustration of cathodic protection of buried a metal pipe.

protection. Because the power source is delivered to the anode and is not generated by its degradation, the impressed current system can be calibrated to meet the site's conditions. Current can be automatically and continuously adjusted to meet varying conditions. The voltage provided by sacrificial anodes is too high when new and too low when old, so the impressed current system provides a means for supplying the right amount of current at all times. However, the best way to avoid corrosion in spillway conduits is not to use metal pipes.

Corrosion of metal parts of operating mechanisms may be effectively treated and prevented by keeping these parts greased and/or painted. Inspectors should look for these signs of preventive maintenance, and recommend that they are implemented if not now used.

Most of the metal corrosion that inspectors find during a visual inspection will be a maintenance concern. Inspectors should be able to recognize when corrosion is a potential safety issue that threatens the safety of the dam. Metal corrosion becomes hazardous when it makes critical metal structures inoperable. Inoperable gates, valves, or cranes and hoists endanger a dam when the ability to release flood flows is hindered, and the dam is in jeopardy of being overtopped. Corrosion that is not particularly severe or extensive may interfere with the operation of moving mechanical parts or cause them to bind.

Metal girders used as supports for an operating or access bridge might buckle if weak-

ened by extensive corrosion and prevent access to the gate and valve controls. Inability to operate spillway gates during a flood could cause the dam to overtop.

Pitting can perforate a metal conduit and allow water to erode an embankment dam from within. Inspectors need to pay careful attention to areas where the coating is missing or defective. A small opening in a coating can result in severe, concentrated corrosion at that spot.

Test the operation of gates and valves at regular intervals and during any comprehensive evaluation inspection. Testing operation is the best way to decide if corrosion is hindering the proper functioning of these devices (the owner should perform all testing).

If metal corrosion is found during an inspection:

- Photograph and record location, type, and extent of the deterioration.
- Note prominent features, and whether another area is damaged.
- Look for structural damage, including misalignment, settlement, vertical and horizontal displacement.
- Look for any surrounding damage to structures or foundation.
- Classify and describe the corrosion using the terminology previously defined.
- Consult a corrosion specialist if:
 - Hazardous metal corrosion may endanger the dam either because the part in question is sensitive to small degrees of corrosion (as in a mechanical device such as a gate) or because the corrosion is severe and extensive enough to cause a metal structure to fail.
 - It is suspected that metal has been lost to corrosion on an inaccessible surface, such as the outside of buried metal conduit. Ultrasonic thickness measuring equipment operated from the opposite side can estimate metal thickness, but the extent of pitting

corrosion is difficult to determine because damage tends to be highly localized. The conduit may need to be excavated for a thorough examination.

- Evaluate pitting, an ordinary form of corrosion, by counting the number of pits (if sites are few) or by using a system of rating charts, which are based on the percentage of pitted area.
- Document all observations and recommend corrective action and timing.

Cracking and Deformation

Cracking in metal is a separation into two or more parts, while deformation is the bending or twisting of a metal object into other than its design shape.

Metal cracking and deformation tend to afflict mechanical devices, such as cranes and hoists, or structures subjected to static and dynamic stress, such as gates and valves. Uneven hoist pull is a cause of gate frame and lifting beam distortion, broken gate connections, and broken lifting chain or wire rope. Deep or extensive cracking is a sign that failure caused by tearing and rupture is pending, while deformations may interfere with mechanical operations. During flooding or other emergencies, inoperable equipment could endanger a dam by being unable to release flood flows.

Metal cracking and deformation usually includes three types of deficiencies: (1) cracking and stress corrosion cracking; (2) fatigue and corrosion fatigue; and (3) overload failure.

Cracking and corrosion in metals may be closely related; stress corrosion cracking and corrosion fatigue involve both corrosion and mechanical forces. Stress corrosion cracking results from a combination of tensile stress and a mildly corrosive environment. Inspectors should look for signs of stress under corroded areas to decide if there was a mechanical force involved that caused fatigue of the metal.

Metal fatigue is a loss of strength from repetitive bending, which known as corrosion fatigue when combined with corrosion. The affected area weakens, cracks, and then tears or ruptures. Sharp notches and reentrant corners without fillets are often points (called “stress risers”) where a crack starts.

An overload failure is the result of a single stressing beyond the tensile, shear, or compression strength of a metal part. An example is the buckling of a conduit or a liner because of an internal vacuum or external pressure.

During dam safety visual inspections, an inspector will see far more corrosion than cracking and deformation of metals. Cracking and deformation usually affect the integrity of a metal part, and therefore are likely to be hazardous to the safety of a dam.

If inspectors discover metal cracking or deformation that may affect the safety of the dam, they should do the following:

- Photograph and record the extent, location, and probable causes of cracks and deformations.
- Compare observations with prior inspection reports
- Consult a qualified dam safety professional for further evaluation and proposed corrective measures.

Metal Coatings

Metal coatings are coating systems that have been specifically formulated to adhere to metal (or other materials) and protect it from corrosion. Metal coating systems for dams and associated structures (penstocks, power plants, administrative and maintenance structures) can be divided into four broad categories:

- 1) Coating systems that will be fully immersed in water or covered with backfill (buried).
- 2) Coating systems that will be both immersed in water and subjected to atmospheric exposure.

- 3) Coating systems that will receive exterior atmospheric exposure only.
- 4) Coating systems that will receive interior atmospheric exposure only

Some coating systems overlap one or more of the above categories. Although it is possible that exposure to severe chemicals, saltwater, severe chemical fumes, or salt spray could occur, and a coating system that would resist these types of exposure would be required, it is not likely that such exposure conditions would be experienced with freshwater dams and dam-related structures in India.

Coating systems control corrosion in one or more of the following ways:

- Creating a barrier between the metal and corrosive agents in the environment. It is important to realize that there is no such thing as a completely and indefinitely impervious coating system.
- Gradually releasing corrosion-inhibiting chemicals.
- Sacrificial action in which the sole or major component of the coating, such as zinc, sacrifices itself to protect the metal underneath. The coating in effect offers a kind of cathodic protection.

Defective or missing protective coatings expose metal parts and structures to corrosion and, therefore, to ultimate failure. Failure of metal structures such as gates, bridges, and conduits can result in dam failures. All coatings systems fail prematurely for one or more of the following reasons:

- Poor surface preparation (very frequent cause)
- Poor application procedures (frequent cause)
- Improper specification of a coating system for the underlying metal or exposure conditions it will be facing in the field (infrequent cause)
- Defective or off-standard coating system materials because of mistakes or contamination during their manufacture (infrequent cause)

- Physical or mechanical damage, resulting from impacts, cavitation, or erosion from water carrying abrasive sediment

Identifying and quantifying metal coating system deficiencies is accomplished by periodic visual inspection of the applied coatings. This inspection is easily carried out on the coating systems that are exposed to the atmosphere, either indoors or outdoors, and are reasonably accessible. Visual inspections of immersed coating systems on gates and the interiors of penstocks can be made when those structures have been dewatered. Buried coating systems on the exteriors of pipe or other structures cannot be directly inspected unless they have been uncovered for some reason. If there is a corrosion monitoring system in place, the coating systems can be indirectly inspected for their general conditions. Among the tools required for the visual inspections are a knife, a magnifying glass, and a thickness gauge. A pitting gauge or other means of measuring, or at least reasonably estimating, the depth of pits is also necessary.

The first areas to exhibit coating failure are usually welds, bolt heads, edges, and areas where access is difficult. The thickness gauge is used to measure decreases in coating system thickness from erosion, chalking, and abrasion. Thicknesses are usually measured in thousandths of an inch (mils). (As a point of comparison, a dollar bill is about 4 mils thick.) Pitting is often the most serious defect and can cause rapid failure of piping or other structures while a major part of the remaining metal is intact. This defect can be serious in a metal conduit running through an embankment dam, for example, because the escaping water can erode the dam from within. Measuring the depth of pits enables a calculation to be made of the pit depth versus the thickness of the steel.

A knife is one of the best and most important inspection instruments for checking corrosion and pitting. It is necessary for removing corrosion so that pitting can be measured, and for removing loose coating system material so that corrosion undercutting of the coating system film can be discov-

ered. A knife is a good instrument for checking adhesion to see how much adequately bonded coating is left if there is local peeling or other signs of removal of the coating system. It can also be used to check flexibility and discover embrittlement of coating system films and to break blisters to check the condition of the metal underneath.

Quantification of coating system defects can be carried out by using ASTM pictorial methods. These methods are available in *Pictorial Standards of Coating Defects* published by the Federation of Societies for Coatings Technology (FSCT 1979). Pictorial standards are available for blistering, chalking, checking, cracking, erosion, filiform corrosion, flaking, mildew, and rusting. Both a number and a description are given, such as No.4-medium dense blisters. Using these standards, it is possible to convey the appearance of a coating system defect to people who have not seen it personally. It is important to record the locations of defects accurately. An imaginary grid system can be used if the location of the grids is recorded. Another method is a verbal description, such as upper left or center left of a gate whose dimensions are given. In pipes, the distance and direction from reference points, such as the pipe outlet or maintenance holes, can be given.

Recording the results of both scheduled and unscheduled coating system visual inspections is extremely important. The records of the coating systems on all structures must begin with the coating systems that were originally applied. A complete history must be kept of all the coating systems that have been applied to the structures, including records of touchups. An existing system must be overcoated or touched up with a compatible coating. The records can track the rate of deterioration of coating systems and make pre-planned maintenance and a recoating possible. Also, the records can supply the information needed for decisions on whether to touch up, repair and overcoat, or remove the existing coating system to metal, prepare the surface, and completely recoat with the same or a different coating system.

Cavitation

Cavitation damage can be detected visually in areas where cavitation is likely to occur. It is distinguished by the loss of material in a pitting pattern which appears as though the lost material was “sucked” off or, in some instances, by removal of the coating system and evidence of an attack on the metal underneath.

Cavitation is likely to occur at the same locations in metal pipes as in concrete pipes, as described earlier. Cavitation may be reduced by introducing air through a vent pipe at a point downstream of the control valve, where a pressure drop is expected. The vent pipe enables atmospheric pressure so that a partial vacuum is not created, and cavitation is avoided. Cavitation is also found on valve surfaces.

6.6.3 Conduit and Pipe Special Concerns

Many dams have conduit systems that serve as principal spillways and outlets. These conduit systems are required to carry normal stream and flood flows safely past the embankment throughout the life of the structure. Conduits through embankments are difficult to construct properly and can be extremely dangerous to the embankment if problems develop after construction. Conduits are usually difficult to inspect and repair because of their location within the embankment. Also, replacing conduits requires extensive excavation. Attention should be directed to maintaining these structures to avoid difficult and costly repairs.

The most frequent problem noted with spillway conduit systems is undermining of the conduit. This condition typically results from water leaking through pipe joints, seepage along the conduit or inadequate energy dissipation at the conduit outlet. The typical causes of seepage and water leaking through pipe joints include any one or a combination of the following factors: loss of joint material, separated joints, misalignment, differential settlement, conduit deterioration, and pipe deformation. Problems in any of these areas

may lead to failure of the spillway system and breaching of the dam.

Undermining is the removal of foundation material surrounding a conduit. Any low areas or unexplained settlement of the earth-fill in line with the conduit may be a sign that undermining has occurred within the embankment. As erosion continues, undermining of a conduit can lead to displacement and collapse of the pipe sections and cause sloughing, sliding or other forms of instability in the embankment. As the embankment is weakened, a complete failure of the conduit system and, eventually the dam may occur. Undermining along the entire length of conduit is referred to as piping.

In addition, undermining can occur as the result of erosion resulting from inadequate energy dissipation or inadequate erosion protection at the outlet. This undermining can be seen at the outlet of a pipe system and can extend well into the embankment. In this case, undermining can lead to other conduit problems such as misalignment, separated joints, and pipe deterioration.

Inspectors should look for signs of undermining and piping, including sinkholes, water seepage, loss of pipe-joint material, sediment build-up at the outlet, and movement of pipe sections.

Seepage along the conduit from the reservoir can occur because of poor compaction around the conduit. If seepage control devices have not been installed, the seepage may remove foundation material from around the conduit and eventually lead to piping. Seepage is usually easy to spot around conduits.

Pipe deformations are typically caused by external loads that are applied to a pipe, such as the weight of the embankment or heavy equipment. The collapse of the pipe can cause failure of the joints and lead to erosion of the supporting fill. This may lead to undermining and pipe settlement. Pipe deformation may reduce spillway capacity. Pipe deformation must be checked on a regular basis to ensure that no further deformation is occurring, that pipe joints are intact and that

no undermining or settlement is occurring. A common cause of pipe deformation is inadequate compaction of fill under and around the conduit.

Conduit systems usually have construction and/or section joints. In all cases, the joints will have a water stop, mechanical seal and/or chemical seal to prevent leakage of water through the joint. Separation and deterioration of the joints can destroy the watertight integrity of the conduit system. Joint deterioration can result from weathering, excessive seepage, erosion or corrosion. Deterioration at joints includes loss of gasket material, loss of joint sealant, and spalling around the edges of joints. Separation at a joint may be the result of a more serious condition such as foundation settlement, undermining, structural damage, or structural instability. Separated pipe joints can be detected by inspecting the interior of the conduit. Both separation and deterioration of joints allow seepage through the conduit. The seepage can erode the fill underneath and along the conduit causing undermining, which can lead to the displacement of the pipe sections or embankment piping. A visual inspection program is needed to determine the rate and severity of joint separation and deterioration. Joint separations should be monitored on a regular basis to determine if the movement is continuing.

Deterioration of conduit material is normally caused by the forces of nature such as wetting and drying, freezing and thawing, oxidation, decay, ultra-violet light, cavitation, and the erosive forces of water. Deterioration of pipe materials and joints can lead to seepage through and along the conduit and eventually failure of conduit systems.

Removal or consolidation of foundation material from around the conduit can cause differential settlement. Inadequate compaction next to the conduit system during construction may compound the problem. Differential settlement can lead to undermining of the conduit system or embankment piping. The differential settlement should be monitored with visual inspections and documentation of observations.

Alignment deviations can be a sign of movement, which may exceed the design tolerances. Proper alignment is important to the structural integrity of conduit systems. Misalignment can be the direct result of internal seepage flows that have removed soil particles or dissolved soluble rock. Misalignment can also result from poor construction practices, the collapse of deteriorated conduits, the decay of organic material in the dam, seismic events, or normal settlement from the consolidation of the embankment or foundation materials. Excessive misalignment may result in other problems such as cracks, depressions, slides on the embankment, joint separation, and seepage. Both the vertical and horizontal alignment of the conduit should be inspected on a regular basis.

All conduits should be inspected thoroughly once a year as part of the scheduled inspection program. Conduits that are 75 cm or more in diameter can be entered and visually inspected with proper ventilation and confined space precautions. Small inaccessible conduits may be monitored with video cameras. The conduits should be inspected for misalignment, separated joints, loss of joint material, deformations, leaks, differential settlement, and undermining.

Problems with conduits occur most often at joints, and special attention should be given to them during the visual inspection. The outlet should be checked for signs of water seeping along the exterior surface of the conduit. This is noted by water flowing from under the conduit and/or the lack of foundation material directly beneath the conduit. The embankment surface should be monitored for depressions or sinkholes. Depressions or sinkholes on the embankment surface above the spillway conduit system develop when the underlying material is eroded and displaced. Inspectors should photograph all problems that are observed in the conduits.

Accessible portions of conduits, such as the outfall structure and control, can be easily and regularly inspected. However, several problems are associated with deterioration or failure of portions of the system which are

either buried in the dam or normally under water. The following are some general guidelines for inspecting conduits:

- Conduits that are 75 cm or greater in diameter can be inspected internally, provided the system has an upstream valve, allowing the pipe to be dewatered. Tapping the conduit interior with a hammer will help locate voids which may exist behind the pipe. This type of inspection should be performed at least once a year during scheduled inspections.
- Small diameter pipes can be inspected by remote video cameras. A camera is moved through the conduit and transmits a picture to an equipment truck, where it can be viewed by a technician. This type inspection is expensive and usually, requires the services of an engineer. However, if no other method of visual inspection is possible, the use of remotely-controlled video equipment is recommended at least once every five years.
- Outlet intake structures, wet wells, and outlet pipes with only downstream valves are the most difficult to inspect because they are usually under water. These should be scheduled for visual inspection when the reservoir is drawn down or at five-year intervals. If a definite problem is suspected, or if the reservoir remains full over extended periods, divers should be hired to perform an underwater inspection.

6.6.4 Testing the Outlet System

Dam drawdown valves and outlets must be operationally tested on an annual basis, between November 1 and March 30, before the onset of the flood season (typically March in India) to verify their performance and to help keep them in operating order. Unused outfall valves and controls can become corroded or blocked with sediment, so routine testing can help maintain these devices. To verify that the valve is still functioning, but to minimize the quantity of silt and/or poor-quality water

that may be released downstream, the following procedure is to be used:

- (1) The area immediately in front of the drawdown structure shall be checked for debris that might be drawn into the opening, and cleared of such debris as much as possible. If there is a reason to believe that sediment may have built up immediately in front of the opening at an elevation equal to the invert of the outlet or higher, the structure shall not be tested until such silt is removed, complying with all regulatory requirements prior to doing so.
- (2) The structure shall be opened a minimal amount, enough to allow a small discharge and then closed fully, to verify ability to operate in that direction.
- (3) The structure shall then be fully opened, and immediately closed again, minimizing the open period as much as possible.
- (4) If there is any sign of erosion occurring downstream during the process, the operation shall be halted and the structure closed. Remedial actions shall be taken to prevent erosion from the flows prior to the test being repeated or completed.
- (5) If the valve fails to fully close, either in steps two or three, an emergency contractor and a dam safety engineer should be immediately notified.

The outlet system should be checked through the full range of gate settings. Slowly open the valve, checking for noise and vibration. Certain valve settings may result in greater turbulence. Check for a noise that sounds like gravel being rapidly transported through the system. This sound indicates that cavitation is occurring. Note the operating range that produces this noise, and, if possible, avoid operating under these gate settings. Check the operation of all mechanical and electrical systems associated with the outlet. Backup electric motors, power generators, and power and lighting wiring should function as intended and be in a safe condition.

The outlet, or lake drain, should always be operable so that the pool level can be drawn down in the case of an emergency or

for necessary repair. Lake drain valves or gates that have not been operated for a long time present a special problem for owners. If the valve cannot be closed after it is opened, the impoundment could be completely drained. An uncontrolled and rapid drawdown could also induce more serious problems such as slides in the saturated upstream slope of the embankment. Drawdown rates should not exceed 1 foot per day for slopes of clay or silt material except for emergency situations. Level surfaces or slopes with free-draining upstream zones may be able to withstand more rapid drawdown rates; however, the owner should consult with CDSO or a qualified dam safety professional before using a more rapid drawdown rate. Large discharges could also cause downstream flooding. Therefore, before operating a valve or gate, it should be inspected and all appropriate parts lubricated and repaired. It is also prudent to advise downstream residents of large and/or prolonged discharges.

To test a valve or gate without risking that the lake will be drained, the inlet upstream of the valve must be blocked. Some drain structures have been designed with this capability and have dual valves or gates, or slots for stoplogs (sometimes called bulkheads) located upstream of the drain valve. Divers can be hired to inspect the drain inlet and may be able to construct a temporary block at the inlet for testing purposes. Early detection of equipment problems or breakdowns and confidence in equipment operability are benefits of the periodic operation.

Sediment is another problem that may be encountered when operating the lake drain. Sediment deposits can build up and block the drain inlet. Debris can be carried into the valve chamber, hindering its function if an effective trash rack is not present. The potential that this problem will occur is decreased if the valve or gate is operated and maintained periodically.

Many older dams have drains with valves at the downstream end. If the valve is located at the downstream end of a conduit extending through the embankment, the conduit is

under the constant pressure of the reservoir. If a leak in the conduit develops within the embankment, saturation, erosion, and eventually failure of the embankment could occur in a brief period of time. A depressed area of the soil surface over the pipe may be a sign soil is being removed from around the pipe. These older structures should be monitored closely, and owners should plan to relocate the valve upstream or install a new drain structure. Inspectors should closely examine the drain outlet for signs of possible problems when valves are located at the downstream end of the drain.

6.6.5 Mechanical Equipment

Mechanical equipment includes spillway gates, sluice gates or valves, stoplogs, sump pumps, flash boards, relief wells, emergency power sources, siphons and other equipment associated with spillways, drain structures, and water supply structures. Stoplogs, flashboards, and siphons are not necessarily mechanical equipment but are included in this category because they could be, and the equipment used to implement them usually is. Mechanical and associated electrical equipment should be checked for proper lubrication, smooth operation, vibration, unusual noises, and overheating. The adequacy and reliability of the power supply should also be checked during operation of the equipment. Auxiliary power sources and remote-control systems should be tested for adequate and reliable operation. All equipment should be examined for damaged, deteriorated, corroded, cavitated, loose, worn, or broken parts.

Gate stems, guides, and couplings should be examined for corrosion, loose, broken or worn parts, and damage to protective coatings. Fluid passages, leaves, metal seats, guides, and seals of gates and valves should be examined for damage from cavitation, wear, misalignment, corrosion, and leakage. Sump pumps should be examined and operated to verify reliability and satisfactory performance. Air vents for pipes, gates, and valves should be checked to confirm that they are open and protected. Wire rope or

chain connections at gates should be examined for proper lubrication and worn or broken parts. Rubber or neoprene gate seals should be examined for deterioration or cracking.

Hydraulic hoists and controls should be checked for oil leaks and wear. Hoist piston and indicator stems should be examined for contamination and for rough areas that could damage packings.

Many dams have structures above and below ground that require some type of access. Water supply outlet thimble works, lake drains, gated opening spillways, drop box spillways, and toe drain utility access hole interceptors are typical structures that will require bridges, ladders, or walkways. Care should be taken to properly design, install, and maintain these means of access for the safety of persons using them. Access requirements for walkways may include toe plates and handrails. Fixed ladders should have proper rung spacing and safety climbing devices, if necessary. Access ladders, walkways, and handrails should be examined for deteriorated or broken parts or other unsafe conditions.

Stoplogs, bulkhead gates, and lifting frames or beams should be examined to find their availability and condition. The availability, operability, and locations of equipment for moving lifting and placing stoplogs, bulkheads, and trash racks should also be verified.

Flashboards are usually wood boards installed in an upright position along the crest of the spillway to raise the normal pool level. Flashboards should not be installed or allowed unless there is enough freeboard pass the design flood safely. Some flashboard installations are designed to fail when subjected to a certain depth of flowing water, thereby recovering the original spillway capacity. However, flashboards designed to fail may not be reliable and are not recommended. Maintenance consists of repairing or replacing broken boards. The support structure for the flashboards should be examined for damage caused by wear, misalignment, corrosion, and leakage, and repaired as necessary. The

flashboards should be removed periodically (at least once a year) as a check for freedom of movement and deterioration of the boards. Leakage is a frequent problem. Unless there are extenuating circumstances, flashboards should be removed prior to the onset of monsoon season (typically March in India) and reinstalled when conditions permit.

6.6.6 Earth and Rock Materials

Earth Spillways

When examining an earth spillway, inspectors should decide if whether side slopes have sloughed, or whether there is excessive vegetative growth in the channel. The entrance and exit of the spillway should be unobstructed by trees, brush, or general vegetative overgrowth; during severe flooding, accumulation of drift in these areas can significantly reduce spillway capacity, increase erosion and contribute to overtopping of the dam and failure. Inspectors also should look for signs of erosion and rodent activities. Use a probe to obtain a comparative feel of the hardness and moisture content of the soil. Note the location of particularly wet or soft spots. See if the stilling basin or drop structure is properly protected with rocks or riprap. Because some erosion is unavoidable during discharge of water, decide if whether such erosion might endanger the embankment. If the spillway is installed with a sill, check to see if there is any cracking or misalignment of the sill. Also, look for any erosion beneath or downstream of the sill.

If spillway side walls slide and block the spillway entrance or channel, the dam may become susceptible to overtopping because of reduced capacity to pass flood flows. Erosion of plunge pools and return channels may expose the toe of the dam to erosion and undercutting which can lead to a slope failure.

Rock Cuts

Dams built in areas where the bedrock is at or near the surface may include outlet works and spillway channels and tunnels constructed in or through the rock. Fallen rock may block discharges through a tunnel or

channel, or rock falling into the reservoir just upstream from the dam could make outlet works, penstocks, or spillways inoperable. Abutment movement may restrict or prevent operation of appurtenances found in or on the abutment. Loosened rock could block or damage structures in their fall paths. Any of these conditions may cause the dam to be overtopped.

Rock deficiencies can be described by one of the following categories:

- Inadequate hardness or strength
- Discontinuities (faults, shears, joints, bedding planes)
- Weathering, or deterioration (temperature variations (thermal stresses), freeze-thaw action, erosion, plant and animal activity, chemical action)
- Solutioning (chemical weathering of mineral or rock into solution by seepage flow)

Excavated rock slopes and tunnel walls are subject to spalling and weathering from freeze-thaw action. The rock has joints (also called fractures or discontinuities) along which water can pass, resulting in deterioration. Movement at these joints caused by an earthquake or from excessive hydrostatic pressure may result in large rock falls.

Inspectors should be alert for potentially large rock falls, slides, and resulting obstruction of tunnels and spillway channels. These potentially hazardous conditions are typically caused by instability of rock slopes, degradation of rock slopes, seepage from cut faces, and deficient rock reinforcement.

Slope instability in rock spillways usually results in slides or movement on the slopes. Look for signs of rock movement at fractures and joints which might be a sign of a future rock fall or slide. Movement is often indicated by fresh cracks on the rock surface, cracks in dam concrete where it joins the rock, blocks falling from abutments, displacement of vegetation, and arc-shaped cracks on or above slopes. Slides on slopes next to spillways are especially hazardous be-

cause of the potential for blockage, or damage to the structure preventing operation. In rock abutments, next to a concrete dam, look for freshly exposed rock at or near the dam body-abutment contact. Check any instrumentation data that may exist for indications that rock walls or slopes have moved. Movement of abutment rock can be serious, resulting in loss of support for the dam. If data show progressive movement and increasing seepage pressure, the dam and abutments may be in danger of destabilization.

Degradation of rock slopes is usually easy to spot. Look for evidence of past rock falls, and check the floors of rock-cut spillways and unlined rock tunnels for excessive amounts of rock chips and pieces. Examine the walls for general deterioration. If there is evidence that portions of a concrete structure have moved because of thermally or chemically induced expansion or other causes, check rock abutments next to the structure for spalling and crushing of rock at joints and fractures caused by pressure from concrete movement.

Seepage from rock cuts or from the floor of spillways cut in rock can create several potentially unsafe conditions. Inspectors should evaluate the rate of seepage, correspondence of seepage rates to reservoir level, staining, and turbidity of seepage to fully understand the problem. Seepage can create excess hydrostatic pressure, weaken the overall strength of the rock walls, and produce increasingly large channels for water flow. Openings can enlarge sufficiently to cause slope movement or collapse. Stains from seepage water indicate solutioning of minerals which may reduce the shearing strength of the rock materials and cause rock consolidation. Inspectors should take samples of the seepage so that tests can be carried out to assess the mineral content of the water.

The geologic data should also be checked for evidence of deposits of limestone or other rock subject to solutioning that may underlie competent rock. Turbid flow is a sign that internal erosion or piping is occurring. Inspectors should check the construction records to see if rock walls and slopes

were grouted to control seepage. If grouting was not done in the past, this procedure might control the seepage. If prior grouting proved inadequate to prevent or control seepage, a qualified dam safety professional should examine probable causes and sources of the seepage and evaluate corrective actions.

Deficient rock reinforcements, if used, can also result in slope stability problems in spillways cut in the rock. Rock reinforcements such as bolts, anchors, dowels, and tendons may be installed in the rock tunnels and slopes of dams. Be sure to make a record of deficient rock reinforcements, including deterioration of the rock around fastening plates, loose bolts or plates, and corroded bolts, fastening plates, or wire grids (especially near seepage).

If inspectors find rock deficiencies that may affect the safety of a dam, they should:

- Record the location and extent of the deficiencies, and photograph the affected areas.
- Ascertain definitely the cause of the damage, if possible.
- Notify a qualified engineer at once if abutment movement or a rockfall in an unlined tunnel or spillway channel is suspected or observed.

Riprap

Riprap is deficient when it does not protect the underlying earth from erosion. Many riprap deficiencies can be dealt with through routine maintenance, such as adding rock to areas where riprap has started to become displaced. More severe riprap deficiencies may threaten the safety of the dam. Undercutting by wave action, slides, and slope failure can lead to failure of a spillway channel, a plunge pool, or, if erosion continues unchecked, even the breaching of an embankment dam or dike.

Riprap may suffer from displacement or rock degradation. These deficiencies may be related, with degradation often leading to displacement. Filter or bedding material may be-

come exposed, or the riprap layer may become thinner, thereby reducing the level of protection offered by the rock coverage. Reasons riprap can be displaced include:

- an inadequate thickness of the riprap layer;
- improper sizing or gradation of the riprap in relation to the filter or bedding material (inner layer is washed through outer layer);
- improper anchorage at the base of the protected slope;
- loss of foundation support;
- missing, inadequate, or improperly sized filter or bedding material;
- wrong shape (too slabby/flat, or too round: most problems are caused by stones being too round and easily rolled by waves or flows);
- rock weight insufficient (because of small size or low specific gravity) for expected wave action or flow velocity;
- too much variance in size and weight;
- average weight reduced by rock deterioration;
- nondurable rock;
- damage from ice movement in the reservoir;
- bedding not properly installed;
- poor grading of the slope;
- improper foundation preparation;
- rock sizes segregated during placement; and
- loose placement that results in large voids.

Rock degradation may be caused by high abrasion loss, structural weakness (cracks and fractures), high absorption rates (freeze-thaw damage from absorbed water), and impact damage from debris. Types of rock degradation include cracking, spalling, splitting or delaminating along bedding planes and joints, de-aggregating and disintegrating of poorly cemented sedimentary rock, and dissolving.

Riprap installations in areas exposed to many freeze-thaw cycles or high winds are most likely to experience serious problems. Be especially alert for riprap problems if the dams being inspected are exposed to these conditions.

Riprap exposed to high-velocity flows or turbulence on a spillway channel, or in the lining of a plunge pool, is especially vulnerable. Rock may be displaced or may degrade by becoming weathered and breaking down, thereby allowing damage to the underlying slope. All riprap degrades over time, but wetting and drying and freeze-thaw cycles accelerate degradation in spillway and outfall structures. Look for signs that the riprap is smaller near the waterline that rocks are shattered, or that thinning of the riprap layer or gaps in the riprap have developed. The riprap layer may be so degraded and displaced that erosion of the underlying material has begun.

If riprap deficiencies that may affect the safety of the dam are found, inspectors should:

- Record the location and approximate dimensions of riprap deficiencies.
- Look for signs of foundation and bedding deterioration.
- Photograph the area.
- Recommend temporary corrective actions.
- Consult a qualified dam safety professional to evaluate the need for major repair.

Gabions

Gabions may be used as lining and support in spillways, stilling basins, and other dam outfall structures. A gabion is a prefabricated rectangular wire cage or basket filled in place with rocks. Gabions are free-draining and capable of being stacked for erosion protection. The term “gabion wall” may be used to refer to stacked gabions, while “gabion mattress” refers to a layer of gabions used to protect a chute or basin floor.

Gabions are usually subject to various deficiencies that may cause deformation and the

toppling of gabion walls. These deficiencies include inadequate foundation support, foundation erosion, settlement of the rock within the basket, rock degradation, and failure of the wire baskets. Settlement and displacement of gabions can result from inadequate foundation support or from erosion of the subgrade. Foundation soils may be eroded when gabions are used because water flow can occur at the bottom of the basket. Proper foundation treatment is essential when gabions are installed in waterways. Rock within a gabion can shift and combine into a smaller space than when the basket was filled, creating unsupported space at the top of the basket. Rocks within gabions may spall, split, disintegrate, or dissolve. Flowing water can then wash pieces of rock through openings in the basket. The loss of rock mass makes the gabions susceptible to being lifted and moved by flows, and consolidation of rock within the basket creates empty, unsupported space at the top of the basket. The wires of the baskets may become corroded, broken or cut by vandals, or deformed by rapidly flowing water. Rocks may be washed out of a damaged basket, and the basket can be deformed by the weight of shifting rocks or other gabions and fail.

Failure of gabion channel protection may result in the exposure of slopes or channel floors to erosion and undercutting, leading to complete failure. When gabion structures consist of stacks or rows of baskets, the integrity of individual baskets is crucial to the integrity of the structure. Baskets are prone to deformation because basket wires can bend, corrode, and break, and stones can shift, deteriorate, or be dislodged.

Some settlement of a gabion installation is normal. Gabions are designed to be flexible and allow for some degree of settling. Minor deterioration in a gabion installation is a long-term maintenance problem rather than a hazard to the dam. Hazardous gabion deficiencies are those that destabilize the installation or cause it to fail entirely, usually because of deficiencies in a limited number of baskets.

The lower baskets in a vertical or battered gabion wall support the greatest weight and

are most likely to become deformed. Because of their position, failure of lower baskets carries the potential to destabilize a gabion installation. Defects such as broken, cut, or deformed wires and missing rock can lead quickly to the failure of an individual gabion followed by the failure of the entire wall. Look for damaged baskets or baskets crushed by overlying gabions, and for movement and undermining caused by waves or current.

If inspectors discover gabion deficiencies that may affect the safety of a dam, they should:

- Record the location and extent of defective areas, and describe the nature of the deficiency; i.e., broken basket wires, the degree of deformation or settlement, and the approximate amount of missing rock.
- If the underlying slope is exposed, record the extent of slope damage, using such measurements as the length, width, and height of the affected area.
- Photograph the damaged area.
- Recommend corrective action and timing.

6.6.7 Synthetic Materials

Synthetic materials are often used in spillways and outlet works for discharge (conduits or pipes), drainage and seepage control (geotextile separators, geomembrane liners), and for filter media. Synthetic materials are also commonly referred to as geosynthetic materials because they are often used to replace earth materials in construction. In general, synthetic materials are not visible for examination during an inspection. Inspectors will detect most deficiencies in synthetic materials by noting indirect signs, such as changes in drainage amounts, or foundation erosion. Synthetic materials used at dams fall into three broad categories: (1) geotextiles, (2) geomembrane linings, and (3) plastic piping and tubing (often referred to as geopipes).

A deficiency in a geotextile or geomembrane lining may severely affect the integrity of the incorporating structure. In the case of

geotextiles within a dam, the deficiency could cause the dam to fail from internal erosion or piping. Deficiencies of geotextiles used for slope protection could result in a slope failure. The deficiency may affect a structure crucial to the safe operation of a dam, such as a spillway or a plunge pool.

Inspectors are usually most successful with detection of deficiencies in geotextiles and geomembrane linings in dams when they record the amount of seepage at drains and check the clarity of the water that is collected. If seepage has decreased and water pressure within the embankment has increased, as measured by a piezometer, geotextiles within the embankment may be clogged. Undrained seepage may be building hydrostatic pressure inside the embankment, weakening soil strength, or eroding the embankment. Turbid flow suggests piping and loss of material.

The following subchapters describe specific safety concerns for the various synthetic materials that may be used at dams and spillways.

Geotextiles

Geotextiles are water permeable, are made from polypropylene or polyester, and can be woven, nonwoven, or a combination of woven and nonwoven segments. Uses for geotextiles include separation between layers of materials, drainage, reinforcement, and filtration. In dams, geotextiles may have temporary or permanent construction uses. Geotextiles placed as embankment dam core and foundation filters would be extremely difficult to replace if problems develop, and such uses have been avoided.

Geotextiles are sometimes used in place of granular filters beneath other erosion control materials such as riprap on the dam embankment or surfaces in spillways and plunge pools. The geotextile filters prevent the movement of soil fines under riprap or similar materials used for slope protection and for lining spillways and plunge pools. Punctures and other deficiencies may result in loss of bedding material and erosion of foundation material beneath the geotextile, leading to sunken areas and voids under the riprap.

When a geotextile fails, the failure may jeopardize the structure which incorporates the geotextile. If seepage in a protected slope is restricted from entering a collector drain because of a clogged geotextile, excessive hydrostatic pressure could develop in the embankment or slope which could lead to slope failure. A ruptured geotextile could lead to internal erosion of the embankment material because the filtering capacity is lost, at least locally.

Clogging of geotextiles under riprap may also cause a buildup of hydrostatic pressure at the toe, saturating the slope, and potentially resulting in a local failure that bulges at the slope toe until the geotextile breaks. After the geotextile breaks, a washed-out area will develop.

If deficiencies in geotextiles that could affect the safety of the dam are found, inspectors should:

- Photograph and record the observations that indicate possible problems with the geotextiles.
- Determine the function of the geotextile and the cause of the problem.
- Refer problems with geotextiles to a qualified dam safety professional.

Geomembranes

Geomembrane linings are impermeable and are typically used as water barriers. Geomembrane linings may be composed of various materials, the most commonly used being PVC (polyvinyl chloride), CSPE-R (chlorosulfonated polyethylene-reinforced), HDPE (high-density polyethylene), VLDPE (very low-density polyethylene), and neoprene. Dams with seepage problems may deploy a geomembrane on the upstream face of the dam to control seepage.

A failed geomembrane reservoir liner can permit seepage through porous foundation zones which might cause piping to develop. For reservoirs sealed with a geomembrane liner, unaccountable losses from the reservoir may be the first clue that the liner is leaking. Seepage around the reservoir rim is another

indicator. Inspectors should examine the reservoir floor with the reservoir drawn down if possible. Examine the protective layer over the membrane liner for gaps, plant growth, animal burrows, damage from vandalism, and piercing of the liner.

If deficiencies in geomembrane linings that could affect the safety of the dam are discovered, inspectors should:

- Photograph and record the observations that show likely problems with the geomembrane linings.
- Determine the cause of the problem.
- Refer indications of geomembrane lining failure to a qualified dam safety professional.

Geopipes

Plastic piping and tubing (geopipes) are often used in dam spillway and outlet works, although this practice is not recommended in India. Furthermore, plastic pipes have not been proven to be safe in spillway applications. Most geopipes are made of PVC (polyvinyl chloride), ABS (acrylonitrile butadiene styrene), and PE (polyethylene).

Plastic pipe is used for conveying water and other fluids, but the pipe must be protected from mechanical damage. Plastic piping and tubing usually are embedded in concrete or buried underground for protection. Common uses for plastic piping and tubing include:

- Piezometer tubing used to measure water pressure in earth structures or foundations and abutments
- Tubing in stilling wells
- Electrical conduit
- Seepage collectors in drainage systems (PE)
- Outlet works conduits (PE and PVC)

Deficiencies of plastic pipes that affect the safety of the dam involve drainage systems. Malfunction of plastic pipes used as seepage collectors in drainage systems could result in excess or leaking drainage water

building hydrostatic pressure inside the embankment, the dam, or in the foundation, causing a loss of strength, reduction of safety against slope failure or sliding, and failure at the downstream toe or slope. Seepage also may erode soil from within the dam or foundation into a broken or damaged collector system.

If plastic pipes are used in any application at a dam or reservoir, a detailed engineering analysis of the application must be performed, and installation techniques must be carefully specified. Only “thick-walled” plastic pipe should be considered for use, and CDSO or a qualified dam safety professional should be consulted prior to its use. In general, the use of plastic pipe for spillway discharge conduits is not recommended.

Inspectors should check for safety deficiencies in plastic pipes used in drainage systems. Past inspection reports and other documentation may contain drainage measurements to compare with current observations. Signs of potentially hazardous conditions in plastic piping and tubing include leaking fittings and joints, visible impact damage, warp or creep, silted or obstructed flow area, plugged outlets obstructing free flow (lack of flow – works only during wet weather), crushed pipe, burned surfaces, and turbidity or sediments in the discharge.

When inspecting unexposed pipe, reduced flow, turbid flow, or lack of flow are indicators of potential problems with the pipe. The following procedures can be used to help identify problems with unexposed or buried pipes:

- Pull a plug through the pipe to test for obstructions (if open at two ends)
- Inspect the pipe interior using a remotely operated video or television camera
- Use a motorized drain cleaning tool to clear obstructions
- For a pipe that should be watertight, pressurize the pipe with air or water, and check the pressure to detect leaks (not recommended unless low pressures are

used, because a sudden break or release could damage the embankment)

If a deficiency in plastic piping and tubing that may affect the safety of the dam is observed, inspectors should:

- Record the observations and procedures used to investigate changes in drainage patterns.
- Describe any findings concerning the causes of the deficiency, and possible corrective actions.
- If the volume of leakage into the embankment is sizable, consult a qualified dam safety professional for further evaluation.

6.7 Obstructions

Obstructions can reduce the capacity or operation of spillways and outlets. Obstructions of surface features are usually easy to detect. However, obstructions within buried or submerged conduits and other structures may not be noticeable. The spillway, the approach to the spillway, and the downstream exit channel could be obstructed by excessive growth of grass and weeds, thick brush, trees, debris, or landslide deposits. An obstructed spillway will have a reduced discharge capacity. This reduced capacity can create serious problems, including embankment overtopping or complete dam failure.

6.7.1 Excessive Vegetation on Auxiliary Spillways

Earthen auxiliary spillways are particularly prone to excessive vegetative growth (Figure 6-4). There should be no trees, shrubs, or brush in any auxiliary spillway. Structures, unless considered in the original design for spillway adequacy, should not be built in auxiliary spillways. Inspectors should always recommend the removal of trees, shrubs, and other obstructions in an auxiliary spillway.

Tall weeds and brush should be periodically cleared and trees removed as soon as they are noticed. Brush and debris can be entangled with trees to form an effective obstruction. When this happens, an even and

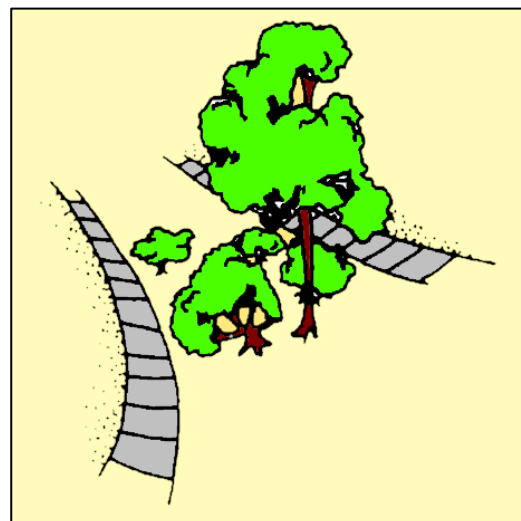


Figure 6-4. Excessive vegetation on earthen auxiliary spillways decreases flow capacity and endangers the dam.

smooth flow pattern cannot be maintained. Consequently, the effective width and capacity of the spillway could be reduced and the potential for erosion increased.

Any large deposits of dirt in the spillway channel from sloughing, a landslide above the channel, or sediment transport into the area must be removed at once. Timely removal of large rocks is especially important. The presence of rocks in the channel can obstruct flow and encourage erosion. A sudden plunge of the spillway to the stilling basin also results in abrasion of the channel lining and damage to the stilling basin.

6.7.2 Plugged Spillway Inlets

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

removed whenever it restricts the inlet capacity.

A well-designed trash rack will stop large debris that could plug the discharge pipe but allow unrestricted passage of water and smaller debris. Some of the most effective trash racks allow flow to pass beneath the trash into the riser inlet as the impoundment fills. Racks usually become plugged because the openings are too small, or the head loss at the rack causes material and sediment to settle out and accumulate. Small openings will stop small debris such as twigs and leaves, which in turn cause a progression of larger items to build up, eventually completely blocking the inlet. Trash rack openings should be at least 15 cm across regardless of the pipe size. The larger the principal spillway conduit, the larger the trash rack opening should be. The largest openings should be used, up to about 0.6 meters.

The trash rack should be properly attached to the riser inlet, and strong enough to withstand the hammering forces of debris being carried by high-velocity flow, a heavy load of debris, and ice forces. If the riser is readily accessible, vandals could throw riprap stone into it. The size of the trash rack openings should not be decreased to prevent such vandalism, but rock that is larger than the openings or too large to handle should be used near the riser.

The lack of a trash rack is unacceptable and creates the potential for an extremely hazardous condition. Trash racks constructed from thin wire, such as “chicken wire,” that can be easily damaged or destroyed is also unacceptable. Trash racks that are “flat” and cover only the opening of a riser (i.e. that are constructed like a grate over a drop inlet on streets) are also safety concerns because of the potential for clogging. In either case, inspectors should recommend the installation of a proper trash rack.

Maintenance should include periodically checking the trash rack for rusted and broken sections, and repairing it as needed. The trash

rack should be checked often during and after large floods to ensure it is functioning properly and to remove accumulated debris.

Vegetated earth spillways are used as an economical means to provide auxiliary spillway capacity. Normal flows are carried by the principal spillway, and infrequent large flood flows pass primarily through the auxiliary spillway. For dams with pipe-conduit spillways, an auxiliary spillway is always needed as a back-up in case the pipe becomes plugged. These spillways are often neglected because the owner rarely sees them flow.

Large semiaquatic rodents may present problems at dams where they may live because they have a natural tendency to block off spillways with brush and sticks. They should be eliminated or moved if they become a problem, or a control device should be constructed at the spillway to prevent their approach.

Periodic mowing in the grass-lined spillways is needed to prevent trees, brush, and weeds from becoming established, and to encourage the growth of grass. A poor vegetative cover will usually result in extensive, rapid erosion when the spillway flows and will require more costly repairs. Trees and brush may reduce the discharge capacity of the spillway. Inspectors should evaluate the degree of vegetative growth in the earthen spillways. Tree and shrub removal should always be recommended if these plants are present.

Erosion can be expected in the spillway channel during high flows, and can also occur because of rainfall and local runoff. The latter is more of a problem in large spillways, creating gullies where low flows tend to concentrate and may need special treatment, such as terraces or pilot channels. Erosion of the side slopes deposits material in the spillway channel, especially where the side slopes meet the channel bottom. In small spillways, this can significantly reduce the spillway capacity. This condition often occurs soon after construction is completed and before vegetation becomes established. In these cases, it may be necessary to reshape the channel to increase its discharge capacity.

Auxiliary spillways often are used for purposes other than the passage of flood flows. Among these uses are reservoir access, parking lots, boat ramps, boat storage, pasture, and cropland. Permanent structures (such as buildings, boat docks, and fences) should not be constructed in these spillways.

During a check of spillways and outlets for obstructions, the inspectors should:

- Describe the location, type, and extent of any obstruction that may be present.
- Photograph the obstruction.
- Recommend corrective action and timing.

6.7.3 Blocked Weepholes

Weepholes, or drain holes, in the concrete allow free drainage and relieve excessive hydrostatic pressures from building up underneath or behind the structure (Figure 6-5). Excessive hydrostatic pressures underneath or behind the concrete could cause it to heave or crack which increases the potential for accelerated deterioration and undermining. Weepholes can become plugged by debris, infiltration of fines, iron incrustation, and carbonate deposits and should be

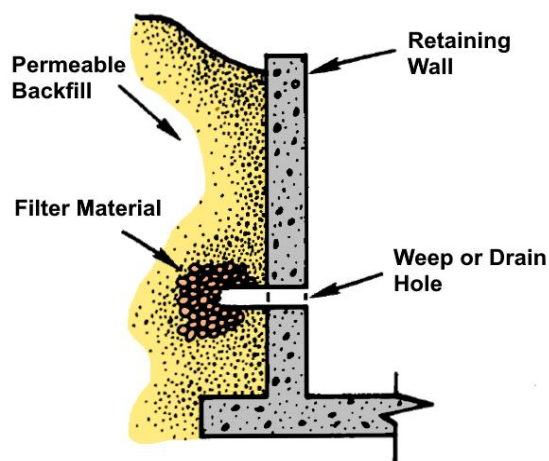


Figure 6-5. Weepholes in spillway sidewalls and bottom slabs can become blocked with debris and other material.

checked for the accumulation of silt and granular deposits at their outlets. These deposits may obstruct flow or be signs of the loss of support material behind the concrete surfaces. Periodic monitoring of the weephole drains should be performed and documented on a regular and routine basis to ensure that they are functioning as designed.

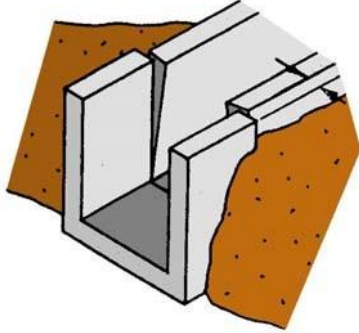
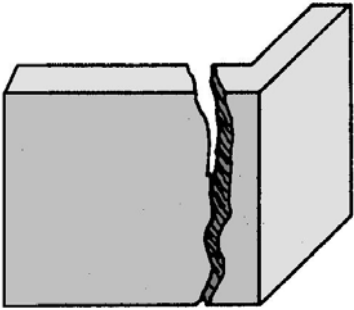
Walls of spillways are usually equipped with weepholes. Occasionally, spillway chute slabs are also equipped with weepholes. If all holes are dry, it is probably because the soil behind the wall or below the slab is dry. If some holes are draining while others are dry, then the dry holes may be plugged by mud or mineral deposits. Probe the plugged hole to determine probable causes of the blockage. Plugged weepholes increase chances for failure of the retaining wall or chute slab. Try to clean out dirt or deposits and restore draining ability. If this does not work, rehabilitation work must be performed under the supervision of a qualified dam safety professional as soon as possible.

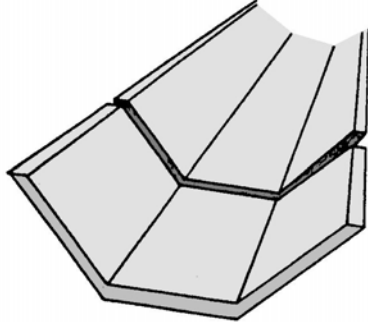
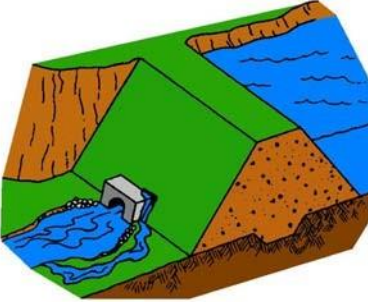
6.8 Spillway and Outlet Inspection Sketches

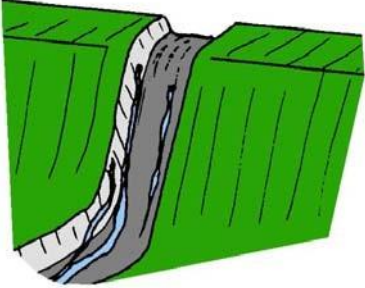
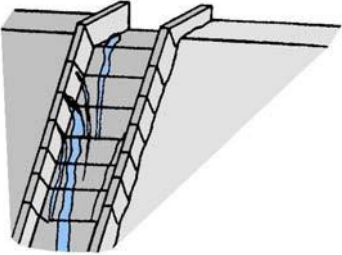
Sketches of problems that may be found on the spillway or outlet of a dam during an inspection are presented in Table 6-1. While most of the conditions on the following tables can be corrected by routine and periodic maintenance conducted by the owner, some of the conditions noted are of a nature that threatens the safety and integrity of the dam and require the attention of a qualified dam safety professional (if immediate emergency action is not necessary).

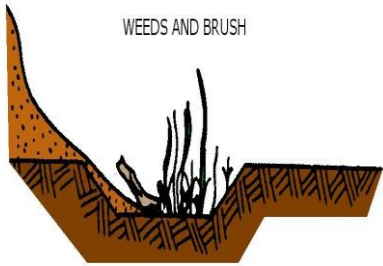
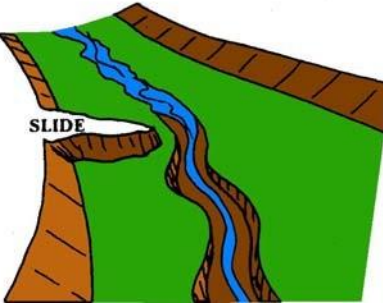
A qualified dam safety professional is a person with specific experience in the field of concern. For example, an engineer or geologist with geotechnical or geological experience may need to be consulted if a slope stability or soil issue exists. Or, an engineer with hydrologic and hydraulic experience may be needed to calculate the spillway capacity.


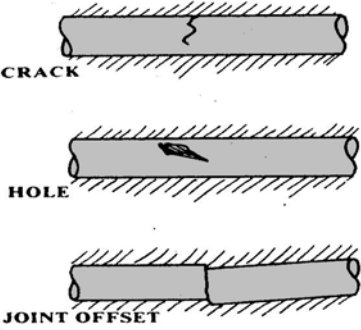
Table 6-1. Sketches of problems that are found at the spillway or outlet of a dam, the hazards created, and remedial measures.

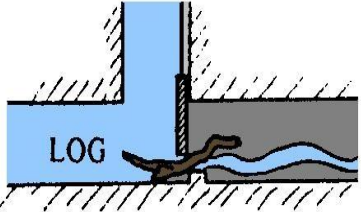
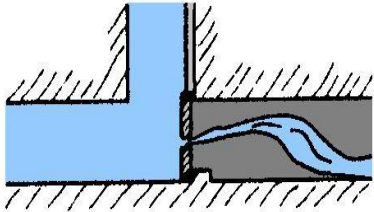
Problem	Probable causes	Hazards created	Remedial measures
 <p style="text-align: center;">Wall Displacement</p>	<ol style="list-style-type: none"> 1. Poor workmanship. 2. Uneven settlement of foundation. 3. Excessive earth and water pressure. 4. Insufficient steel bar reinforcement of concrete. 	<ol style="list-style-type: none"> 1. Minor displacement will create eddies and turbulence in the flow causing erosion of the soil behind the wall. 2. Major displacement will cause severe cracks and eventual failure of the structure. 	<ol style="list-style-type: none"> 1. Reconstruction or replacement should be done according to sound engineering practices. Foundation should be carefully prepared. 2. Adequate weepholes should be installed to relieve water pressure behind the wall. Use enough reinforcement in the concrete. 3. Anchor walls to prevent further displacement. 4. Installation of struts between spillway walls is required. 5. Clean and backflush the drain to assure proper operation.
 <p style="text-align: center;">Large Cracks</p>	<ol style="list-style-type: none"> 1. Construction defect. 2. Local concentrated stress. 3. Local material deterioration. 4. Foundation failure. 5. Excessive backfill pressure. 	<ol style="list-style-type: none"> 1. Disturbance in flow patterns. 2. Erosion of foundation and backfill. 3. Eventual collapse of structure 	<ol style="list-style-type: none"> 1. Large cracks without large displacement should be repaired by patching. Surrounding areas should be cleaned or cut out before patching material is applied. 2. Installation of weepholes or other actions may be needed. 3. Replacement may be required in some cases.

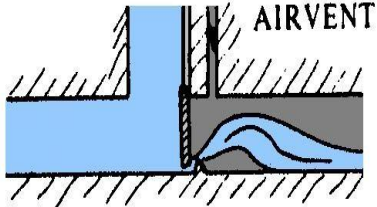
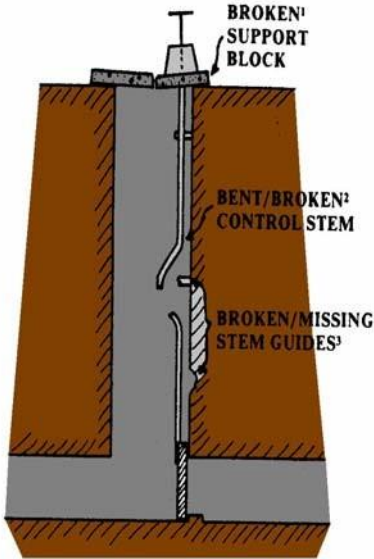
Problem	Probable causes	Hazards created	Remedial measures
 <p>Open or Displaced Joints</p>	<ol style="list-style-type: none"> Excessive and uneven settlement of the foundation. Sliding of a concrete slab. Construction joint too wide and left unsealed. Construction joint sealant deteriorated and washed away. 	<ol style="list-style-type: none"> Erosion of foundation material may weaken support and cause further cracks. Pressure induced by water flowing over displaced joints may wash away wall or slab, or cause extensive undermining. 	<ol style="list-style-type: none"> Construction joint should not be wider than 0.5 inches. All joints should be sealed with asphalt or other flexible materials. Water stops should be used where feasible. Clean the joint, replace eroded materials, and seal the joint. Foundation should be properly drained and prepared. The underside of chute slabs should have ribs of adequate depth to prevent sliding. Avoid steep chute slope.
 <p>Seepage Water Exiting from a Point Next to the Outlet</p>	<ol style="list-style-type: none"> A break in the outlet pipe. A path for flow from the reservoir has developed along the outside of the outlet pipe. 	<ol style="list-style-type: none"> Continued flows can lead to rapid erosion of embankment materials and failure of the dam. 	<ol style="list-style-type: none"> Thoroughly investigate the area by probing and/or shoveling to see if the cause can be determined. Decide if leakage water is carrying soil particles. Measure the discharge. If flow increases or is carrying embankment materials, reservoir level should be lowered until leakage stops. A qualified engineer should inspect the condition and recommend further actions to be taken.

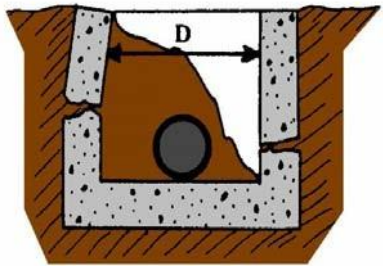
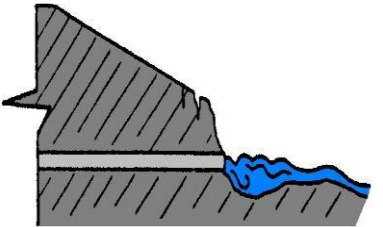
Problem	Probable causes	Hazards created	Remedial measures
 <p>Leakage in or Around the Spillway</p>	<ol style="list-style-type: none"> 1. Cracks and joints in geologic formation at spillway are allowing seepage. 2. Gravel or sand layers under the spillway are letting water seep through the embankment. 	<ol style="list-style-type: none"> 1. Could lead to excessive loss of stored water. 2. Could lead to a progressive failure if velocities are high enough to cause erosion of natural materials. 	<ol style="list-style-type: none"> 1. Examine exit area to see if the type of material can explain the leakage. 2. Measure flow quantity and check for the erosion of natural materials. 3. If flow rate or amount of eroded materials increases rapidly, reservoir level should be lowered until flow stabilizes or stops. 4. A qualified engineer should inspect the condition and recommend further actions to be taken.
 <p>Seepage from a Construction Joint or a Crack in the Sidewalls or Floor of the Spillway</p>	<ol style="list-style-type: none"> 1. Water from the reservoir is collecting behind or under structure because of insufficient drainage or clogged weepholes. 2. Lack of cutoff wall. 	<ol style="list-style-type: none"> 1. Can cause walls to tip in and over. Flows through concrete can lead to rapid deterioration from weathering. 2. If the spillway is within the embankment, rapid erosion can lead to failure of the dam. 	<ol style="list-style-type: none"> 1. Check area behind the wall for puddling of surface water. 2. Check and clean as needed: drain outfalls, flush lines, and weepholes. 3. If condition persists, a qualified engineer should inspect the condition and recommend further actions to be taken

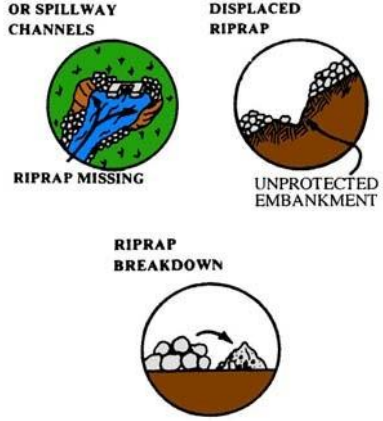
Problem	Probable causes	Hazards created	Remedial measures
 <p style="text-align: center;">Debris or Other Obstructions in the Spillway</p>	<ol style="list-style-type: none"> 1. Accumulation of slide materials. 2. Dead trees. 3. Excessive vegetative growth in spillway channel. 	<ol style="list-style-type: none"> 1. Reduced discharge capacity. 2. Overtopping of the spillway sidewalls. 3. Overtopping of the dam. 4. Prolonged overtopping can cause failure of the dam. 	<ol style="list-style-type: none"> 1. Clean out debris periodically. 2. Control vegetative growth in spillway channel. 3. Install log boom in front of spillway entrance to intercept debris.
 <p style="text-align: center;">Earth Slide in Discharge Channel</p>	<ol style="list-style-type: none"> 1. Discharge velocity too high. 2. Bottom and slope material are loose or deteriorated. 3. Channel and bank slopes too steep. 4. Bare soil unprotected. 5. Poor construction. 6. Protective surface failed. 7. Engaged too often. 	<ol style="list-style-type: none"> 1. Disturbed flow pattern. 2. Loss of material 3. Increased sediment load downstream. 4. The collapse of banks. 5. Failure of the spillway. 6. Can lead to the rapid evacuation of the reservoir through the severely eroded spillway. 	<ol style="list-style-type: none"> 1. Minimize flow velocity by proper design. 2. Use sound material. 3. Keep channel and bank slopes mild. 4. Encourage growth of grass on the soil surface. 5. Construct smooth and well-compacted surfaces. 6. Protect surface with riprap, asphalt, or concrete. 7. Repair eroded part using sound construction practices.

Problem	Probable causes	Hazards created	Remedial measures
 <p>Undercut Downstream End of Spillway Chute</p>	<ol style="list-style-type: none"> 1. Poor configuration of the stilling basin area. Highly erodible materials. The absence of a cutoff wall at the end of the chute. 	<ol style="list-style-type: none"> 1. Structural damage to spillway structure; the collapse of slab and wall; leads to a costly repair. 2. Higher velocity flows can cause erosion of drain, then embankment materials. 	<ol style="list-style-type: none"> 1. Dewater affected area; clean out eroded area and properly backfill. 2. Improve stream channel below the chute. 3. Apply properly sized riprap in stilling basin area. 4. Install cutoff wall.
 <p>Outlet Pipe Damage</p>	<ol style="list-style-type: none"> 1. Crack: Settlement; impact, improper design or placement. 2. Hole: Rust (steel pipe) Erosion (concrete pipe) Cavitation 3. Joint offset: Settlement or poor construction practice. 	<ol style="list-style-type: none"> 1. Creates a passageway for water to exit or enter the pipe. 	<ol style="list-style-type: none"> 1. Check for evidence of water either entering or exiting the pipe at a crack or hole. 2. Tap pipe near the damaged area and listen for a hollow sound which shows that a void has formed along the outside of the conduit. 3. If a progressive failure is suspected, ask for qualified professional help.

Problem	Probable causes	Hazards created	Remedial measures
 <p style="text-align: center;">Debris Stuck Under Gate</p>	<ol style="list-style-type: none"> 1. The trash rack is missing or damaged. 	<ol style="list-style-type: none"> 1. Gate will not close. 2. Gate or stem may be damaged in an effort to close the gate. 	<ol style="list-style-type: none"> 1. Raise and lower gate slowly until debris is loosened and floats past valve. 2. When the reservoir is lowered, repair or replace the trash rack.
 <p style="text-align: center;">Cracked Gate Leaf</p>	<ol style="list-style-type: none"> 1. Ice action. 2. Rust 3. Impact 4. Vibration. 5. Stress resulting from forcing gate closed when it is jammed. 	<ol style="list-style-type: none"> 1. Gate-leaf may fail completely, evacuating reservoir 	<ol style="list-style-type: none"> 1. Use valve only in fully open or closed position. 2. Minimize the use of the valve until the leaf gate can be repaired or replaced.

Problem	Probable causes	Hazards created	Remedial measures
 <p>Damaged Gate Leaf or Guide</p>	<ol style="list-style-type: none"> 1. Rust. 2. Erosion. 3. Cavitation. 4. Vibration. 5. Wear 	<ol style="list-style-type: none"> 1. Leakage and loss of support for gate leaf. 2. The gate may bind in guides and become inoperable. 	<ol style="list-style-type: none"> 1. Minimize use of valve until guides/seats can be repaired. 2. If cavitation is the cause, check to see if air vent pipe exists, and is unobstructed.
 <p>Control Works</p>	<ol style="list-style-type: none"> 1. BROKEN SUPPORT BLOCK: Concrete deterioration. Excessive force exerted on control stem by attempting to open the gate when it was jammed. 2. BENT/BROKEN CONTROL STEM: Rust. Excess force used to open or close gate. Inadequate or broken stem guides. 3. BROKEN/MISSING STEM GUIDES: Rust. Inadequate lubrication. Excess force used to open or close gate when it was jammed. 	<ol style="list-style-type: none"> 1. BROKEN SUPPORT BLOCK: Causes control support block to tilt; control stem may bind. Control headworks may settle. The gate may not open all the way. Support block may fail completely, leaving outlet inoperable. 2. BENT/BROKEN CONTROL STEM: Outlet is inoperable. 3. BROKEN/MISSING STEM GUIDES: Loss of support for control stem. The stem may buckle and break under even normal use, (as in this example). 	<ol style="list-style-type: none"> 1. Any of these conditions can mean the control is either inoperable or at best partially operable. 2. Use of the system should be minimized or dropped. If the outlet system has a second control valve, consider using it to regulate releases until repairs can be made. 3. Engineering help is recommended.

Problem	Probable causes	Hazards created	Remedial measures
 <p>Failure of Concrete Outfall Structure</p>	<p>1. Excessive side pressures on the unreinforced concrete structure. Poor concrete quality.</p>	<p>1. Loss of outfall structure exposes embankment to erosion by outlet releases.</p>	<p>1. Check for progressive failure by monitoring typical dimension, such as "D" shown in the problem sketch. 2. Repair by patching cracks and providing drainage around the concrete structure. Total replacement of outfall structure may be needed.</p>
 <p>Outlet Releases Eroding Toe of Dam</p>	<p>1. Outlet pipe too short. Lack of energy-dissipating pool or structure at the downstream end of the conduit.</p>	<p>1. Erosion of toe over-steepens downstream slope, causing progressive sloughing.</p>	<p>1. Extend pipe beyond toe (use a pipe of same size and material, and form a watertight connection to existing conduit). 2. Protect embankment with riprap over a suitable bedding.</p>

Problem	Probable causes	Hazards created	Remedial measures
 <p style="text-align: center;">Breakdown or Loss of Riprap</p>	<ol style="list-style-type: none"> Slope too steep; material poorly graded; failure of sub-grade; flow velocity too high; improper placement of material; bedding material or foundation washed away. Use of unsound or defective materials; structure subjected to freeze-thaw cycles; improper maintenance practices; harmful chemicals. 	<ol style="list-style-type: none"> The erosion of channel bottom and banks; the failure of the spillway. The life of the protected structure will be shortened. 	<ol style="list-style-type: none"> Design a stable slope for channel bottom and banks. Riprap material should be well graded (the material should include small, medium, and large particles). Sub-grade should be properly prepared before placement of riprap. Install filter fabric if necessary. Control flow velocity in the spillway by proper design. Riprap should be placed according to specification. Services of an engineer are recommended. Avoid using shale or sandstone for riprap. Add air-entraining agent when mixing concrete. Use only clean, excellent quality aggregates in the concrete. Steel bars should have at least 25 mm of concrete cover. Concrete should be kept wet and protected from freezing during curing. Timber should be treated before use.

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Chapter 7. INSPECTING GENERAL AREAS

Inspectors should examine other areas around the dam and reservoir while performing routine reviews. An awareness of the complete dam environment will help the owner maintain a dam and be able to make improvements if conditions warrant. The following features and areas should be examined during every routine dam inspection:

- Access
- Shoreline
- Reservoir area
- Submerged areas
- Watershed and tributary channels
- Mechanical and electrical systems
- Instrumentation
- Retaining structures
- Downstream hazards
- Downstream channel obstructions
- Upstream and downstream dams
- Bridge pier alignment and settlement
- Natural features, such as springs, sink-holes, rock outcrops

Inspectors should examine these features and areas and record any changes or concerns in the inspection report. Photographs should be taken of problem conditions, and measurements of some problems may need to be made, such as slides on shoreline slopes, or cracks in access roads. Measurements and photographs will allow an inspector to monitor changes from one inspection to the next. Recent aerial photographs are helpful in evaluating changing conditions in the upstream and downstream watersheds. The dam owner should be alerted to any conditions that may present a potential safety hazard. Deteriorated access roads, unauthorized activities, large landslides, upstream and downstream development, and severe sediment buildup are potentially hazardous concerns.

Access to the dam, the reservoir, and the appurtenant works is important for several reasons, including dam maintenance, dam inspections, dam emergencies, and use of the dam and reservoir for its intended purpose. Inspectors should visually check all adjacent roads and access roads to the dam and crest and assess them for emergency access potential. They should note any deterioration and obstructions that may be present, and record them in the inspection report. Photographs should be taken for damaged road sections, and corrective measures recommended.

The shoreline and reservoir area should be checked for erosion, landslides, cracks, whirlpools, debris, burrowing animals, sediment buildup, and changes made by people such as building construction. Landslides into the reservoir can reduce the storage capacity which, in the worst case, may cause the dam to be overtopped during large floods. Signs of landslides include embankment cracking, scarps, and sloughs. Steep slopes along the shoreline are particularly vulnerable to slides.

Inspectors should also look for sign of seepage from slope areas. Whirlpools in the reservoir near the dam are a sign of leaks or piping in the bottom of impoundment or along submerged outlets.

Burrowing animals should be watched because if they live in the embankment area, they may cause serious harm.

Erosion along the shoreline will result in more sediment entering the reservoir and filling up water storage space, as well as reducing the available reservoir area.

Submerged areas of the reservoir should be checked for sediment (when possible), debris, and excessive vegetative growth, including algae. Sediment from upstream areas is an ongoing problem in most reservoirs and is difficult, if not impossible to stop. When sediment deposits become severe, they should be removed; the usual method is dredging.

Although sediment buildup is a concern because it diminishes the value and use of the reservoir, it normally does not affect the dam's stormwater storage capacity unless the sediment levels rise above the normal water level. Algae are not normally a safety concern, but they make the reservoir unsightly. Safe treatments for algae are available. Algae are often caused by excessive soil nutrients being carried into the reservoir by stormwater runoff, usually from farm fields and lawns.

If the dam or reservoir includes mechanical and electrical features, they should be inspected for disrepair and deterioration. This includes items previously discussed, including spillway gates, sluice gates or valves, stoplogs, flashboards, relief wells, and siphons. It also includes emergency power sources, guardrails along roads, signage, buried cables and utilities, outfall pipes, and conduits entering the reservoir. All mechanical and electrical equipment should be operated at least once per year, and preferably more often. The tests should be conducted by the dam owner or operator and should include the full operating range of the equipment under actual operating conditions.

Each operating device should be permanently marked for easy identification, and all operating equipment should be kept accessible. All controls should be checked for proper security to prevent vandalism, and all operating instructions and manuals should be checked for clarity and maintained in a secure, but readily accessible location.

Inspectors should always check instrumentation that may be used to monitor dam performance or dam safety concerns. This includes items such as piezometers, inclinometers, tiltmeters, weirs, flumes, and flow meters. This equipment should be inspected to make sure it is in good condition and has not deteriorated or been damaged.

Retaining walls are often constructed along shorelines, discharge areas, and other dam areas to help stabilize steep slopes, or to support features such as roads, buildings, and parking lots. The retaining walls should be checked for potential stability concerns, such

as structural cracking, horizontal displacement or tilting, settlement, erosion of the foundation area, and uncontrolled seepage. The failure of a retaining wall may create potential safety hazards, especially if they support parking areas and roads, or if the failure results in a large landslide into the reservoir.

The upstream watershed should be checked primarily for new development which can increase the amount of runoff that enters the reservoir. Impervious areas, such as parking lots, rooftops, and roads will dramatically increase the amount and rate of runoff. Construction sites that disturb large areas of soil will also result in increased runoff as well as increased sediment. New dams in the upstream watershed may also impact the dam that lies downstream. Dams and reservoirs will alter the runoff patterns and the timing of the peak runoff rates. Urban development in the watershed can increase the size of flood peaks and the volume of runoff, thereby making a previously acceptable spillway inadequate. The dam hydrologic and hydraulic analyses may have to be updated if the upstream development is significant, or if a new dam is constructed upstream. Improvements to the dam appurtenant facilities, such as spillway size, outfall linings, and embankment top elevation may have to be implemented if the development creates a significant increase in inflow to the reservoir.

Downstream development may create new safety hazards for the dam owner if the dam would fail. New houses, roads, and other buildings that are occupied by people may change the hazard classification of the dam if these features are within the area which would be inundated if the dam failed. New features must be reported to the dam owner as soon as they are found.

Downstream channel obstructions, including dams, can have an impact on the reservoir discharge if the new facilities are close enough. Tailwater that backs up from dams and other obstructions during floods may reduce the discharge capacity of the upstream dam, especially if the upstream dam has a conduit spillway. The hydrologic and hydrau-

lic calculations for the new features, if performed, should take the upstream dam into account. Tailwater from obstructions should be carefully evaluated to determine if it will impact the upstream dam discharge structures.

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Chapter 8. VISUAL INSPECTION USING REMOTELY OPERATED VEHICLES (ROVs)

Remotely operated vehicles are vehicles that are controlled by an operator who is not in the vehicle. These can be controlled by radio or through a cable or line connecting the vehicle to the operator's location. A remotely operated underwater vehicle (ROUV), more commonly called an ROV, is a tethered underwater mobile device. An unmanned aerial vehicle (UAV), usually called a "drone," is a remotely controlled aerial vehicle.

8.1 Use of Remotely Operated Underwater Vehicles (ROVs)

Over the past four decades, ROVs have become a well-proven part of basic toolkits for working underwater in a wide variety of environments. In many cases, the impetus behind adopting and evolving this technology has been to reduce the risks and costs involved in using divers to perform these tasks. In other cases, the ROV is asked to do things that divers were never able to do.

The use of ROVs for visual inspection of dams (Figure 8-1) is a practice that is becoming increasingly practical (International Water Power and Dam Construction 2016). The main use of ROVs for dam safety inspections is obtaining a visual record of underwater structural damage along the dam face and at



Figure 8-1. An observation class ROV equipped with a high definition video camera, high-intensity LED illumination, and a sonar mapping system.

outlet structures, and sediment deposition around the inlets of low-level sluices.

Although ROV technology cannot replace all the services offered by commercial divers, it can help reduce inspection-related overheads. ROVs can be configured with a high-definition (HD) video camera with high intensity LED illumination, a sonar mapping system, and other tools to navigate and collect valuable information in conditions unsafe for diver entry. ROVs also offer the possibility of streaming live data back to the control station.

Some limitations of ROVs are:

- restricted mobility in fast currents,
- difficulty staying in position in turbulent flows, and
- reduced visibility in the turbid/murky water.



Figure 8-2. In the case of a four-propeller UAV system (quadcopter) such as the one shown, diagonal pairs of propellers spin in opposite directions.

8.2 Use of Unmanned Aerial Vehicles (UAVs)

Dam inspections are applications perfectly suited to the use of UAVs (drones), such as the rotary system shown in Figure 8-2. Using drones to video and scan for cracks, erosion, corrosion and defects in areas that would



Figure 8-4. An inspection drone at work photographing the downstream face of the Tseuzier Dam in Valasi, Switzerland.

otherwise require an inspector to climb, repel, hang from a rope/harness or erect scaffolding is a safer and faster way to carry out a visual examination. Visual inspections also include many exterior features that are crucial to the safety and integrity of a dam that are easily viewed by drones including spillway gates, tunnels, downstream slopes, surge tanks and remote locations on penstocks. Visual inspection by a drone of the upstream face of an arch dam is shown in Figure 8-4. Other uses for drones include aerial photography, construction monitoring, and monitoring of a dam and reservoir during flooding.

Some benefits of UAV inspections of dams include:

- Portability – Drones come in a variety of sizes. Rotary system UAVs that are well-suited for dam inspection range in width from about 0.3 to 0.5 meters and are easily transported to the site (Figure 8-3).
- Speed – Once on site, a drone can be deployed in a matter of minutes, and with no need to put clearances or hold orders in place. Depending on what is being inspected, the set up for a rope access inspection could take several hours to ensure the safety of the climber and all others involved.
- Agility – Drones can perform emergency inspections in hard to reach locations or in areas that are unsafe to place personnel.
- Cost Savings – Rope-access inspections are expensive. Drone use is more cost effective.



Figure 8-3. Rotary system drones suitable for dam inspection are small and easily transported.

Chapter 9. DOCUMENTING AN INSPECTION

The purpose of a visual inspection is to find deficiencies that potentially affect the safety and operation of the dam. An inspector should draw up a systematic procedure for inspecting a dam to ensure that all features and areas are examined and to make efficient use of time spent in the field. First, the earlier inspection reports should be reviewed to note any areas that will require special attention. However, the inspection should not be limited to the items covered only in past inspections. Second, inspection equipment should be assembled, necessary file reviews should be performed, relevant people should be interviewed, and arrangements should be made to access the dam site. Then, a plan of action should be prepared for the visual inspection of the dam. Finally, the inspection should be documented.

Additional provisions may be needed, including such things as mowing the grass or clearing brush on the embankment, shutting off outlet flows, pumping down low areas with standing water, or opening gates and drawdown valves. Concrete dams may require attention and access provisions.

9.1 Method of Documentation

It is important for the dam owner/operator to keep records throughout the entire life of the dam. Accurate records can better illustrate the dynamic nature of the structure and will help pinpoint problems. The dam owner should create a permanent file in which to keep inspection records, including documentation of actions taken to correct conditions found in the inspections. Chapter 3. gives details on the type and extent of records that should be kept in the project file.

9.1.1 Inspection Checklist

A convenient way of compiling inspection observations is by recording them directly onto an inspection checklist. The checklist should be attached to a clipboard and carried

by dam inspectors as they traverse the entire structure. An example of a detailed checklist can be found in Appendix B as Part 2a of the *Scheduled Dam Safety Inspection Form*. It is wise to complete a checklist for comprehensive evaluation inspections and scheduled inspections. A checklist will not typically be needed for informal and special inspections.

Each type of inspection may have its own checklist format, and the format used for an inspection may be predetermined by the owner or CDSO. The benefits of using a checklist include: 1) a checklist is easy to follow, and comprehensive (if properly prepared); and 2) a checklist allows an inspector to make comments or take photographs in response to a predetermined list of features and conditions at the dam.

The inspection checklist should be included in the dam inspection report and is required in the report that is submitted to the CDSO for high hazard dams.

9.1.2 Field Sketches

A good practice to follow along with filling out the inspection checklist is to draw a field sketch of observed conditions. The field sketch is intended to supplement the information recorded on the inspection checklists; however, it should not be used as a substitute for clear and concise inspection checklists. Problems and their location can be recorded on the field sketch. This record may be prepared for any type of inspection.

9.1.3 Photographs

Inspection photographs can be vitally important. Over time, photographs serve to provide a pictorial history of the evolving characteristics of a dam. The dam owner/operator often finds them to be great money savers because they can illustrate that some observed conditions (such as seepage and foundation movement) have existed for many years and may have reached a state of

equilibrium. With this knowledge, quick and economical remedial actions can be developed and implemented. Photographs should be dated on the back (if they are not in digital format) and provided with brief descriptions of the locations shown in the pictures.

9.1.4 Monitoring Data

It may become necessary to make measurements of assorted items during the course of a dam inspection. This may include measurements of seepage rates, spillway discharge rates, settlement, upstream and downstream water levels, and for some dams, readings from instruments such as piezometers. It is important that this data also be compiled in a systematic manner and placed in a permanent file.

9.1.5 Inspection Report Form

Current CDSO regulations require the completion and submittal of a *Scheduled Dam Safety Inspection Report Form* (shown in Appendix B) for comprehensive evaluation inspections on high hazard dams. A detailed written report incorporating the Inspection Report Form, a summary of findings, recommendations, conclusions, photographs, and other supporting data must be prepared for comprehensive evaluation inspections.

9.1.6 Notebooks

An inspector may choose to keep a field notebook that documents all of the observations and findings in addition to a checklist. Notebooks offer convenient records of dam inspections if they are formatted in a logical manner and are thorough.

9.1.7 Voice Recorders

Tape recorders, especially the micro- recorders, can be convenient when it is difficult to write while an inspector is observing field conditions.

9.1.8 Smartphones and Laptop Computers

Smartphones, tablets, and laptop computers are convenient tools for entering field inspection data in reports being prepared in the office. While laptop or notebook computers have traditionally been used for data collection, advances in smartphones and tablets make them an excellent choice for the field. Smartphones have a variety of peripherals available and can operate for weeks between charging or battery replacement. One of the biggest advantages and potential for smartphones lies in their capabilities for customization.

9.1.9 Global Positioning Sensors (GPS)

Handheld GPS units (included with most smartphones) are commonly used to record coordinates (location) and sometimes elevation (more expensive units) of physical earth features, such as dam deficiencies, spillway location and extent, and limits of other appurtenant features. They can be particularly useful for monitoring the progression of deficiencies such as seepage areas, cracks, sloughing, and erosion.

9.1.10 Inspection Notes

Whatever the form of the documentation, inspectors should record their observations in the form of written and digitally-recorded notes. These notes should include information that can be used later to write an inspection report, a letter to the dam owner, a *Dam Safety Inspection Report Form*, or a memo to the project files. The inspection notes should be clear and specific, leaving absolutely nothing to memory. They should be organized in such a way that they document the present condition of each feature of the dam. In addition, any potential problem or defect that was recognized during the records review should be noted and, during the inspection, its current condition should be recorded. The information recorded in written or voice-recorded notes should typically include:

- Names and responsibilities of the inspection team members.
- Climatic conditions, especially rainfall (amounts if known), just prior to and at the time of the inspection.
- Operating conditions such as reservoir and tailwater elevation, spillway and outlet discharge.
- The condition of all inspected features.
- Any mechanical or electrical features.
- All location, elevation, and other descriptive information.
- All quantitative measurements, including instrumentation readings and surveying results (if taken).
- Safety hazards that could pose a threat to the public or project personnel.
- Descriptions of changes in the upstream and downstream areas.
- Notations on any verbal information gathered, prior to or during the inspection, from operating staff and other individuals who are not members of the inspection team.

Unless the dam owner or a regulatory agency has a specific policy on how notes will be taken, inspectors will need to decide whether to use written or tape-recorded methods for recording information during the inspection. Inspectors should not rely solely on the use of voice-recorded notes. If an inspector chooses to voice record most of the inspection notes, some data should also be recorded in a written format to serve as a backup in case problems are encountered with the tape-recorded notes. The joint use of written and voice-recorded notes will allow an inspector to take advantage of the good points of both methods.

9.2 Visual Inspection Documentation

Visual records should always be made to supplement a visual inspection. This form of record keeping illustrates any features or phenomena that an inspector observes during a

dam safety inspection. The three types of visual records used during a dam safety inspection are 1) photographs, 2) video recordings and 3) annotated drawings and sketches. Each of these three types of records can be an effective means of recording information and should be included as part of the report.

Photographs are an excellent means of note taking, and they offer a permanent record of current conditions for future comparisons. A digital camera should be used to take photographs during an inspection. These cameras typically have provisions for zooming in to magnify the features being filmed. It is often hard to describe in words what can be captured in a single photograph.

It is helpful to make a written or voice-recorded note of the picture number, what the photograph portrays, where the photograph was taken, and the direction from which the photograph was taken and other reference information. Having notes about the photographs taken will help an inspector remember valuable information about the photographs after they are developed.

A large variety of photographs should be taken during each inspection, including both wide-angle shots and close-up shots of features. In addition, it may be helpful to take a series of photographs that later can be taped together (or “stitched” together in the case of digital images) to create a panoramic view of the dam and its features.

When choosing the position from which to take photographs, select the camera angle that best illustrates the feature being inspected. Whoever is reading the final inspection report should be able to understand what an inspector is trying to illustrate about each feature. The photographs should present an accurate, pictorial essay of what an inspector or other team members saw. The pictures should visually recreate the inspection so that the readers feel as if they were at the dam site.

There are three camera positions that are typically used when taking photographs:

- 1) A similar position as before: This allows comparison with the latest photographs with earlier ones.
- 2) A different angle than before: This allows a different aspect of the feature to be viewed compared to what was photographed previously.
- 3) A variety of angles: This allows the feature to be studied from several different directions to highlight the different surrounding characteristics.

A thorough study of earlier photographs provides an excellent method of reviewing the condition of the soon-to-be-inspected dam. Such careful review of previous pictures is also important so that an inspector can take photographs of the dam features from similar perspectives.

One other factor that should be taken into consideration when choosing camera position is the quality of available light. Poor lighting will result in poor pictures. Choose the camera position to make the most of angle and lighting. Also, watch out for shadows that will block out key details or the sun in the camera lens.

It is always helpful to include recognizable objects in the photographs, providing, whenever possible, references for location and scale. For detail photographs, the scale can be indicated by using a familiar object such as a pencil or notebook and placing it next to the object to be photographed. A measuring tape or ruler, if properly placed, can help show the approximate size of such aspects as a joint opening or the width of a crack.

A video camera, especially with audio recording, is effective for recording either general or specific coverage of a dam's features. Divers often will use a closed-circuit television camera during an inspection to make a video recording. The use of closed-circuit television cameras offers two benefits: it documents the inspection, and it allows for instructions to be given to the divers. Closed circuit television cameras can also be used to record the conditions inside a conduit, which

cannot be accessed by an inspector. It is important to include references for location and scale in the video recording using the same techniques that are used for still photographs. Location references can be achieved by beginning with a broad shot of the area to be filmed and then slowly changing to a close-up shot. Measuring devices or common objects can be used to show the dimensions of a feature or deficiency. If a measuring instrument is used, make sure it is large enough to be seen on the video.

There are both advantages and disadvantages to documenting an inspection with video recording. The quality of a video record is often not as good as that of photographs unless it is a modern digital camera. It is hard to compare earlier photographs or old video recordings with more recent video. This difficulty may lessen an inspector's ability to recognize the changes that have taken place over time. However, the ability to combine audio and visual records is a definite advantage. The audio part of a video recording can be an excellent means of documenting the sounding of concrete structures with a hammer or bonker while photographing the location and visual appearance of the concrete surface. Even if a video recording is used to document a dam safety inspection, inspectors should also take still photographs.

Drawings and sketches provide graphic representations of a dam feature or condition that is being evaluated during an inspection. Drawings are often effective forms of note taking because they can document and show the location of a deficiency. In general, three types of drawings are useful for inspection documentation:

- 1) Sketches can be drawn of major features or of a localized area of interest. It is important to record the precise location (e.g., station, elevation, and monolith number) of the feature being sketched. This information will be needed if an inspection report is prepared.

- 2) Existing drawings (e.g., a standard sketch of the dam or reduced as-built plan or elevation view of the dam) can be used to make notes about a feature or to record surveying notes, measurements, or other information. A circle or an arrow can be used to highlight the features or areas of concern.
- 3) Aerial photographs of the dam or appurtenant works are now readily available and can be used to locate specific features accurately.

9.3 Writing an Inspection Report

Inspectors should first gather all the information that will be used in the report. The notes developed during the initial data review and onsite inspection are two essential elements. All other pertinent data and photographs that are gathered, analyzed, or reviewed should also be included.

Inspectors should examine their inspection notes before leaving the dam site or shortly thereafter, to make sure that they understand the notes while their memories are still fresh. They should also ensure that all noted deficiencies are described fully and documented with photographs, including the precise location and important quantitative measurements. Voice-recorded notes should be transcribed, and the printed version should be reviewed. Often the transcriber (if other than an inspector) will not be able to understand everything an inspector has said.

Inspectors should compare their written or transcribed notes with the photographs. Comparing the photographs to the notes helps to ensure that the notes are complete and accurate. Photographs may reveal concerns that were overlooked in the notes. It is important for inspectors to label photographs while the information is fresh in their minds. If video recording is used, it is wise to review the video now. It may be useful to have other inspection team members review the notes. The goal is to make sure that the notes are complete before report writing begins.

The next step is to evaluate all the information that has been gathered. The amount and kinds of information collected may vary depending on the type of inspection conducted and inspection policies and procedures. After the onsite inspection is completed, an inspector may need to evaluate the information collected during the inspection using the information contained in the project file to understand the situation fully. This evaluation can also be done in the field. The results of this type of assessment may point to another area of the dam or feature to verify or explain an observed condition. Evaluating the information gathered allows inspectors to put their thoughts together and develop tentative conclusions and recommendations. Inspectors should think about the significance of their findings before writing about them.

An inspector must integrate the findings from the data review with the observations made in the field to evaluate the information collected. Field measurements should be checked against design or as-built plans, if available. Instrument readings taken during the inspection should be checked against previous records. Comparisons should be made between previously reported deficiencies and current conditions. The status of previously recommended follow-up actions should be determined. An evaluation of both previous and current data can help identify trends and can be used to assess the seriousness of any deficiencies observed.

The depth and scope of an inspection report depend on the type of inspection that was performed. For example, an initial comprehensive evaluation inspection report typically requires a greater level of detail and explanation than a scheduled or informal dam safety inspection report. In addition, an initial comprehensive evaluation inspection report will be broader in scope because it includes a comparison of design and construction data against current criteria. The greatest differences among types of inspection reports are the degree to which project features are described and the extent to which design and construction data are analyzed. The depth of a report's conclusions and recommendations

also may vary depending on the type of inspection performed and the extent to which data were reviewed during the inspection. A comprehensive data review will enable an inspector to draw conclusions that are more thorough and to make recommendations that are more extensive. Although the extent and scope of inspection reports may differ, a comprehensive description of the conditions observed during the onsite inspection should be included in all reports.

The format of the report is dictated by the type of inspection performed (i.e., formal technical, maintenance, informal, special) and will determine how the content of the report is to be organized. The comprehensive evaluation inspection report will be the most comprehensive, while a special or informal inspection report may be brief, and may consist of only a letter with attached field notes and photographs. Appendix XXX contains a sample outline of a detailed inspection report that should be included with comprehensive evaluation inspections and submitted to CDSO for all high hazard dams.

9.3.1 Comprehensive Inspection Report

A comprehensive evaluation inspection report needs to be a complete written and bound document that includes at least the following components:

- 1) A title sheet that includes all the following information:
 - a. The name of the dam.
 - b. The state inventory identification number.
 - c. The county and river or stream where the dam is located.
 - d. The owner's and operator's names, addresses, and telephone numbers.
 - e. The date of inspection.
 - f. The name, address, registration number, and signature of the licensed professional engineer
- 2) An executive summary.
- 3) A table of contents.
- 4) A background section that includes the history of construction including completion date, ownership, operation and any past modifications, problems, incidents and/or failures on the structure.
- 5) A project information section that includes all of the following dam specific information:
 - a. The geologic setting and general site conditions.
 - b. The purpose of the dam.
 - c. A description of the dam, spillway system, and other principal features, together with pertinent data.
 - d. A summary of available design, geotechnical, maintenance, construction, repair, and alteration information.
 - e. A reference to past inspection reports.
 - f. A map that shows the location of the dam.
- 6) A field inspection section that includes the following:
 - a. A completed Dam Inspection Report (Scheduled Dam Safety Inspection Form).
 - b. A description of the physical condition of all features of the dam and appurtenant structures, including the impoundment level, as they were observed during the field inspection.
 - c. A description of the downstream area with particular emphasis on existing hazards and changes from previous inspections.

who is in charge of the inspection report.

- d. Dated and captioned photographs of the dam, its appurtenances, the downstream channel, and all deficiencies cited in the report.
 - e. The justification for increasing the overall condition rating and/or increasing the evaluation of a condition on any components from the previous inspection.
- 7) A structural stability section that includes a visual assessment of the stability of the dam based on available data, together with the observations of the field inspection and the results of any calculations performed including a summary description of pertinent available information, such as any of the following:
- a. Geotechnical design data
 - b. Seismic considerations
 - c. Seepage
 - d. Slope stability analysis
 - e. Previous evaluations
- 8) A hydrologic and hydraulic section that includes a visual assessment of the adequacy of the spillway system based on available data, together with the observations of the field inspection and the results of any calculations performed including a summary description of pertinent available information, such as any of the following:
- a. Hydrologic design data
 - b. Drainage area
 - c. Changes in the watershed
 - d. Floods of record
 - e. Previous evaluations
- 9) An operation and maintenance section that includes all of the following:
- a. An assessment of operating equipment and procedures
 - b. Evaluation of the current maintenance plan
 - c. Recommended changes to operation and maintenance procedures
- 10) An emergency preparedness and security section.
- 11) An overall evaluation of the structure's condition, spillway capacity, operational adequacy, and structural integrity based on current inspection, past performance history, existing documentation and recent analyses.
- 12) A determination of whether deficiencies exist that could lead to the failure of the structure.
- 13) Recommendations with a schedule to complete for:
- a. Maintenance, repairs, and alterations to the structure to eliminate deficiencies, including the recommended schedule for necessary upgrades to the structure
 - b. Further detailed studies or investigations
 - c. An assessment of the adequacy of the current hazard potential classification if appropriate
- 14) Appendices that include all the following:
- a. Engineering plans for the dam, if available, or sketches of the dam and its principal parts, including a plan view and cross-sectional views of pertinent features
 - b. If there have been changes to the dam because the submittal of previous plans or sketches, supplemental plans or sketches that depict the changes shall be included
 - c. If engineering plans or sketches have been submitted in a previous inspection report and if there have been no changes to the dam, it is not necessary to submit duplicate plans or sketches in subsequent reports

- d. Supporting documentation for any of the parts within this section

The comprehensive dam safety inspection report must be submitted to the CDSO and the SDSO for all high hazard dams.

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APPENDIX A. INSPECTION FIELD KIT EQUIPMENT

General Inspection Equipment

Inspection Checklist – Serves as a reminder to inspect for all important conditions. An example is presented in Appendix B.

General Embankment Sketch – A sketch of a typical dam embankment may be used to denote the location and dimensions of deficiencies on the embankment and abutments of the dam. A ruler may be useful for scaling dimensions on the sketch. A high-resolution aerial photograph of the dam is recommended for use during dam inspections.

Notebook and Pencil – It is important to write down observations at the time they are made. This reduces mistakes and the need to return to the area to refresh an inspector's memory. A clipboard can provide a sturdy writing surface.

Voice Recording Device – A small portable voice recorder can be used effectively to make a record of field observations when it is not convenient to make written notes. Most smartphones can record voice messages.

Camera – Photographs offer a reliable record of observed field conditions. They can be valuable in comparing past and present configurations. An inexpensive model usually takes pictures good enough for inspection records. Modern digital cameras are excellent for the development of comprehensive photographic records.

Hand Level – This is needed to find areas of interest accurately and to determine embankment heights and slopes. A surveying rod (stadia rod) or another type of measuring rod is a useful aid in making measurements.

Probe – A probe gives information on conditions below the surface, such as the depth and softness of a saturated area. Also, by observing moisture brought up on the probe's surface, an inspector can decide whether an area is saturated or simply moist. Probes with

a metal tip are preferred. An effective and inexpensive probe can be made by removing the head from a golf club.

Tape Measure – Many descriptions are not accurate enough when estimated or paced. The tape measure provides accurate measurements which allow meaningful comparisons to be made.

Flashlight – The interior of an outlet in a dam can often be inspected adequately without crawling through by using a good flashlight or fluorescent lantern.

Shovel – A long-handled shovel is useful in clearing drain outfalls, removing debris, and locating monitoring points. A short-handled shovel may suffice and is more convenient to carry.

Rock Hammer – Questionable-looking riprap or concrete can be checked for soundness with a rock hammer. Care must be taken not to break through thin spots or cause unnecessary damage.

Bonker – The condition of support material behind concrete or asphalt faced dams cannot be found out by observing the surface or facing. By firmly tapping the surface or the facing material, conditions below can be determined by the sound produced when the material is tapped. Facing material supported fully by fill material produces a “click” or “bink” sound while facing material that is over a void or hole in the facing produces a “clonk” or “bonk” sound. The bonker can be made of 30 mm diameter hardwood dowel with a metal tip firmly affixed to the tapping end. A rubber shoe like those on some furniture legs is recommended for the other end to allow the bonker to be used as a walking aid on steep, slippery slopes.

Binoculars – These are useful for inspecting limited access areas especially on concrete

dams. They are also helpful for inspecting risers and trash racks that are not accessible from the dam embankment.

Bucket and Timer – These are used to make approximate measurements of seepage or leakage flows. Calculating the time needed for the seepage flow to fill the bucket enables an inspector to calculate the number of gallons per minute. Various container sizes may be needed, depending on the flow rates. More exact measurements can be made with a flow meter when the discharges are large.

Stakes and Flagging Tape – These are used to mark areas requiring future attention

and to stake the limits of existing conditions, such as cracks and wet areas, to allow future comparison.

Knife or Machete – These tools can be useful for clearing weeds and brush, and for scraping rocks or soil.

First-Aid Kit – A basic first-aid kit should be part of every dam inspection kit in case of injury. At a minimum, it should include assorted bandages, antiseptic medicine, pain relief tablets, sunburn lotion, ice packs, a splint, sterilized gauze, scissors, tweezers, and sterilized tape.

Special Equipment

Video Camera – A video camera, preferably digital, can be used to record the entire site; this may be especially useful for concrete and masonry dams or spillways where access is difficult. A high-power magnification can be useful when video recording concrete and masonry dams. Most video cameras are equipped with sound and date recorders.

Inclinometer – An inclinometer is used to make quick measurements of embankment slopes.

Flow Meter – This instrument is used to measure flow velocity and quantity. The flow must be large; small amounts of seepage cannot be measured with a flow meter.

TV Monitor – A TV monitor is used to view and record conditions inside pipes and conduits that are inspected with a video camera mounted on a remote-controlled vehicle.

Two-way Radios – These are useful for communications when more than one inspector is present on large sites.

Confined Space Access Equipment – This includes equipment for personnel access to vertical risers or discharge conduits where emergency retrieval may be necessary. This includes such things as ropes, harnesses, and ladders. It also includes portable gas meters for testing confined spaces for harmful

gasses that may be present. These may be required when entering discharge structures under the ground.

Boats – A boat may be required for access to areas on the reservoir, including shorelines and spillways.

Piezometer Gage or Water Level Indicator – Used to measure depth to water in piezometer or water wells.

Laptop Computers – These portable computers are a convenient tool for making field inspections cost effective and efficient. The computers must have software that is designed for dam inspections and must be compatible with other office equipment so that the information can be readily transferred to the inspection report. Pocket PC's are often referred to as "PDA's."

Global Positioning Sensor (GPS) – Handheld GPS units are recommended for use in mapping deficiencies found during inspections, such as areas where water is seeping from the ground, slides, and cracks. GPS units can be used to monitor the progression of deficiencies over a period of time if they are accurate enough. GPS units access GPS satellites to determine the user's position. The best units can be used to find both spatial coordinates and ground surface elevation.

Safety Equipment and Protective Clothing

Hard Hat – A hard hat is recommended for inspecting large outlets or when working in construction areas.

Rope – Can be used when inspecting steep slopes or conduits. A rope can also be used when inspecting areas along the shoreline. Another person should be present to assist with using a rope.

Insect Repellent – Biting insects can reduce the efficiency and effectiveness of an inspector and sour his disposition. Ticks and mosquitoes can cause skin irritations and severe health problems in some instances.

Snake Bite Kit – In areas where poisonous snakes might be present, a snake bite kit should be included in the first-aid kit; protective leg guards are also available.

Watertight Boots - These are often needed when inspecting various areas of the dam site where standing water is present. Waist-high waders are useful for riser inspection.

Steel-toed Shoes – Steel-toed shoes should be used when there is a danger of debris falling on an inspector's feet.

Sturdy Hiking Boots – Hiking boots may help prevent slipping and falling when traversing slopes and wet areas. Good ankle support can aid in preventing injury to ankles.

Life Jacket – A life jacket is a safety measure to be used when inspecting areas where there is a danger of falling into the water, especially along the shoreline of a deep reservoir, or a reservoir with steep upstream slopes. They are a necessity if an inspector is using a boat.

Smartphone – A smartphone can come in handy in emergencies or when additional information is needed from the office or the owner's office.

Safety Glasses – May be needed in some cases for eye protection.

Gloves – May be useful if stakes are being installed, or if riprap and deteriorated concrete are being investigated.

Reflective Safety Vest or Coat – If inspections are performed during hunting seasons, bright colored clothing is a good preventative measure to avoid shooting accidents.

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APPENDIX B. SCHEDULED DAM SAFETY INSPECTION FORM

A form designed for use during scheduled dam safety inspections – which includes pre- and post-monsoon inspections – follows. The form contains a comprehensive checklist (Part 2a) of items that are found at dams that need to be evaluated during a safety inspection. The checklist consists of (1) a series of questions that need to be answered as Yes/No/Not Applicable for each inspection item, (2) a remarks box in which critical aspects can be commented upon following each question, and (3) a final condition assessment (Unsatisfactory/Poor/Fair /Satisfactory) for that inspection item. Not all inspection items will be found at a dam. The form concludes with a Consolidated Dam Health Status Report (Part 2b).

DRAFT

Scheduled Dam Safety Inspection Form

Part 1a - Inspection Details:

Dam Name:		Project ID Code (PIC):	
Dam Type:		Dam Purpose:	
Dam Owner:		Hazard Classification:	
Dam Operator:		Inspection by:	
City/State/PIN:		Date of Inspection:	
District:		Reservoir Level:	
Latitude:		Auxiliary Spillway Level:	
Longitude:		Weather Conditions:	

Part 1b - Inspection Remarks:

Please provide any additional information or comments not covered by Part 1a form above.

Part 2a - Inspection Checklist:

SN	Inspection Item	Response ^a			Remarks	Condition ^b
		Y	N	NA		
A		Reservoir				
A1.1	<u>General Condition</u>					Unsatisfactory/Poor/ Fair/Satisfactory
1.1.1	Is the reservoir water level unusually high or low?					
1.1.2	Are there signs of decline in water quality?					
1.1.3	Are there signs of recent sediment deposition?					
1.1.4	Is floating debris present?					
1.1.5	Are there people or livestock in and around reservoir?					
1.1.6	Any other issues?					
B		Dam and Dam Reach (Embankment)				
B1.1	<u>General Condition</u>					
1.1.1	Any major alterations or changes to the dam since the last inspection?					
1.1.2	Is there any new nearby development in the downstream floodplain?					
1.1.3	Any misalignment of poles, fencing or walls due to dam movement?					

SN	Inspection Item	Response ^a			Remarks	Condition ^b
		Y	N	NA		
B1.2	<u>Upstream Slope</u>					
1.2.1	Any signs of bulging or concavity (depressions)?					
1.2.2	Presence of longitudinal or transverse cracks?					
1.2.3	Any signs of distress to the stability of slopes?					
1.2.4	Any other signs of structural distress or instability?					
1.2.5	Trees or profuse growth of weeds/bushes at any location?					
1.2.6	Is there evidence of livestock on the upstream slope?					
1.2.7	Are ants, termites, crabs or other burrowing animals present?					
1.2.8	Any degradation to slope protection (rip-rap)?					
1.2.9	Any other issues?					
B1.3	<u>Crest of Dam</u>					
1.3.1	Any signs of excessive or uneven settlement?					
1.3.2	Presence of longitudinal or transverse cracks?					
1.3.3	Presence of undulations, local depressions or heaving?					

SN	Inspection Item	Response ^a			Remarks	Condition ^b
		Y	N	NA		
1.3.4	Any degradation to access road (sealed/unsealed)?					
1.3.5	Evidence of livestock on dam crest?					
1.3.6	Trees or profuse growth of weeds/bushes at any location?					
1.3.7	Any degradation to edges of dam crest or reduction in width?					
1.3.8	Any degradation to upstream parapet or downstream curb wall?					
1.3.9	Any other issues?					
B1.4	<u>Downstream Slope</u>					
1.4.1	Any signs of bulging or concavity (depressions)?					
1.4.2	Any wet patches (seepage), concentrated leaks or evidence of boiling?					
1.4.3	Presence of longitudinal or transverse cracks?					
1.4.4	Any signs of distress to the stability of slopes?					
1.4.5	Are of rain cuts/erosion channels present at any location?					
1.4.6	Any other signs of structural distress or instability?					
1.4.7	Trees or profuse growth of weeds/bushes at any location?					

SN	Inspection Item	Response ^a			Remarks	Condition ^b
		Y	N	NA		
1.4.8	Is there evidence of livestock on the downstream slope?					
1.4.9	Are ants, termites, crabs or other burrowing animals present?					
1.4.10	Any other degradation to slope protection (turfin)?					
1.4.11	Any other issues?					
B1.5	<u>Breaching Section</u>					
1.5.1	Any difficulties in accessing the breaching section?					
1.5.2	Evidence of recent degradation?					
1.5.3	Any other issues?					
B1.6	<u>Junction with Masonry/Concrete Dam Section</u>					
1.6.1	Any presence of leaks, springs or wet spots in the vicinity of the junction?					
1.6.2	Any presence of cracking, settlement or upheaval of earthwork?					
1.6.3	Any evidence of erosion or slope instability?					
1.6.4	Any other issues?					
B1.7	<u>Abutment Contacts</u>					

SN	Inspection Item	Response ^a			Remarks	Condition ^b
		Y	N	NA		
1.7.1	Any presence of leaks, springs or wet spots in the vicinity of the abutment?					
1.7.2	Any presence of cracking, settlement or upheaval of earthwork?					
1.7.3	Any evidence of erosion or slope instability?					
1.7.4	Trees or profuse growth of weeds/bushes?					
1.7.5	Any degradation to up/downstream slope protection (rip-rap, turfing)?					
1.7.6	Any other issues?					
B2	Dam and Dam Block/Reach (Concrete/Masonry)					
B2.1	<u>General Condition</u>					
2.1.1	Any major alterations or changes to the dam since the last inspection?					
2.1.2	Is there any new nearby development in the downstream floodplain?					
2.1.3	Any misalignment of poles, fencing or walls due to dam movement?					
B2.2	<u>Upstream Face</u>					
2.2.1	Evidence of surface defects (honey-combing, staining, stratification)?					
2.2.2	Concrete/masonry deterioration (spalling, leaching, disintegration)?					

SN	Inspection Item	Response ^a			Remarks	Condition ^b
		Y	N	NA		
2.2.3	Is cracking present (structural, thermal, along joints)?					
2.2.4	Evidence of differential settlement (displaced/offset/open joints)?					
2.2.5	Presence of vegetation (growth in joints between blocks)?					
2.2.6	Evidence of any other damage to joints and/or waterstops?					
2.2.7	Any other issues?					
B2.3	<u>Crest of Dam</u>					
2.3.1	Evidence of differential settlement (displaced/offset/open joints)?					
2.3.2	Presence of cracking (structural, thermal, along joints)?					
2.3.3	Profuse growth of weeds/grass/plants at any location?					
2.3.4	Any degradation to access road?					
2.3.5	Any degradation to upstream parapet or downstream curb wall?					
2.3.6	Any other issues?					
B2.4	<u>Downstream Face</u>					
2.4.1	Evidence of surface defects (honeycombing, staining, stratification)?					

SN	Inspection Item	Response ^a			Remarks	Condition ^b
		Y	N	NA		
2.4.2	Concrete/masonry deterioration (spalling, leaching, disintegration)?					
2.4.3	Presence of cracking (structural, thermal, along joints)?					
2.4.4	Evidence of differential settlement (displaced/offset/open joints)?					
2.4.5	Presence of vegetation (growth in joints between blocks)?					
2.4.6	Evidence of any other damage to joints and/or waterstops?					
2.4.7	Excessive seepage/sweating at any location on downstream face?					
2.4.8	Significant leakage at any location on downstream face?					
2.4.9	Any other issues?					
B2.5	Abutment Contacts					
2.5.1	Any presence of leaks, springs or wet spots in vicinity of abutment?					
2.5.2	Any presence of cracking or settlement?					
2.5.3	Profuse growth of weeds/grass/plants at any location?					
2.5.4	Any other issues?					
C1	Gallery/Shaft and Drainage (Embankment)					

SN	Inspection Item	Response ^a			Remarks	Condition ^b
		Y	N	NA		
C1.1	<u>General Condition</u>					
1.1.1	Slushy condition or water logging immediately downstream of dam?					
1.1.2	Any evidence of boiling in vicinity of dam toe?					
C1.2	<u>Gallery/Shaft Condition</u>					
1.2.1	Any problems accessing or inspecting gallery/shaft (obstruction)?					
1.2.2	Any safety issues (inadequate handrails, lighting or ventilation)?					
1.2.3	Problems of inadequate drainage (slippery stairs, water logging of gallery)?					
1.2.4	Evidence of differential settlement (displaced/offset/open joints)?					
1.2.5	Excessive seepage/sweating at any location along gallery/shaft?					
1.2.6	Significant leakage at any location along gallery/shaft?					
1.2.7	Any other issues?					
C1.3	<u>Drain Condition</u>					
1.3.1	Is the flow in the drain unusually high or low?					
1.3.2	Any reduction/deterioration in the drain section or slope?					

SN	Inspection Item	Response ^a			Remarks	Condition ^b
		Y	N	NA		
1.3.3	Presence of debris or profuse growth of weeds/bushes at any location?					
1.3.4	Any other obstruction to the flow of the drain?					
1.3.5	Is the flow in the drain noticeably sporadic/irregular?					
1.3.6	Does the drainage water have high turbidity (high sediment load)?					
1.3.7	Any other issues?					
C2	Gallery/Shaft and Drainage (Concrete/Masonry)					
C2.1	<u>General Condition</u>					
2.1.1	Slushy condition or water logging just downstream of dam?					
C2.2	<u>Gallery/Shaft Condition</u>					
2.2.1	Any problems accessing or inspecting gallery/shaft (obstruction)?					
2.2.2	Any safety issues (inadequate handrails, lighting or ventilation)?					
2.2.3	Problems of inadequate drainage (slippery stairs, water logging of gallery)?					
2.2.4	Evidence of surface defects (honeycombing, staining, stratification)?					
2.2.5	Concrete/masonry deterioration (spalling, leaching, disintegration)?					

SN	Inspection Item	Response ^a			Remarks	Condition ^b
		Y	N	NA		
2.2.6	Presence of cracking (structural, thermal, along joints)?					
2.2.7	Evidence of differential settlement (displaced/offset/open joints)?					
2.2.8	Evidence of any other damage to joints and/or waterstops?					
2.2.9	Excessive seepage/sweating at any location along gallery/shaft?					
2.2.10	Significant leakage at any location along gallery/shaft?					
2.2.11	Any other issues?					
C2.3	<u>Drain Condition</u>					
2.3.1	Is the flow in the drain unusually high or low?					
2.3.2	Presence of calcium or other deposits in drain?					
2.3.3	Any other evidence of the drain being blocked/having reduced section?					
2.3.4	Is the flow in the drain noticeably sporadic/irregular?					
2.3.5	Does the drainage water have unusual color (leachate)?					
2.3.6	Any other issues?					
D1	Spillway and Energy Dissipation Structure					

SN	Inspection Item	Response ^a			Remarks	Condition ^b
		Y	N	NA		
1.1	<u>Spillway</u>					
1.1.1	Any problems inspecting spillway (obstructed access, damaged catwalk)?					
1.1.2	Any obstructions in or immediately downstream of the spillway?					
1.1.3	Evidence of abrasion, cavitation or scour on glacis (e.g. exposed reinforcement)?					
1.1.4	Presence of displaced, offset or open joints?					
1.1.5	Presence of cracking (structural, thermal, along joints)?					
1.1.6	Evidence of surface defects (honeycombing, staining, stratification)?					
1.1.7	Concrete/masonry deterioration (spalling, leaching, disintegration)?					
1.1.8	Presence of vegetation (growth in joints between blocks)?					
1.1.9	Evidence of any other damage to joints and/or waterstops?					
1.1.10	Excessive seepage/sweating at any location on spillway glacis?					
1.1.11	Significant leakage at any location on spillway glacis?					
1.1.12	Any other issues?					

SN	Inspection Item	Response ^a			Remarks	Condition ^b
		Y	N	NA		
D1.2	<u>Energy Dissipation Structure</u>					
1.2.1	Any problems inspecting energy dissipation structure?					
1.2.2	Any obstructions in or immediately downstream of dissipation structure?					
1.2.3	Evidence of abrasion, cavitation or scour on dissipation structure?					
1.2.4	Presence of displaced, offset or open joints?					
1.2.5	Presence of cracking (structural, thermal, along joints)?					
1.2.6	Evidence of surface defects (honeycombing, staining, stratification)?					
1.2.7	Concrete/masonry deterioration (spalling, leaching, disintegration)?					
1.2.8	Presence of vegetation (growth in joints between blocks)?					
1.2.9	Evidence of any other damage to joints and/or waterstops?					
1.2.10	Any problems with under-drainage (blockage of open drain holes)?					
1.2.11	Any other issues?					
E1	Intake/Outlet and Water Conveyance Structure					
E1.1	<u>Intake/Outlet Structure</u>					

SN	Inspection Item	Response ^a			Remarks	Condition ^b
		Y	N	NA		
1.1.1	Any problems inspecting intake/outlet structure (obstructed/unsafe access)?					
1.1.2	Any obstructions in, upstream or downstream of intake/outlet structure?					
1.1.3	Evidence of abrasion, cavitation or scour on intake/outlet structure?					
1.1.4	Any evidence of structural distress (displaced/offset/open joints, cracking)?					
1.1.5	Any evidence of surface defects and/or concrete/masonry deterioration?					
1.1.6	Any other issues?					
E1.2	<u>Water Conveyance Structure</u>					
1.2.1	Any problems inspecting intake/outlet structure (obstructed/unsafe access)?					
1.2.2	Any obstructions in, upstream or downstream of water conveyance structure?					
1.2.3	Evidence of abrasion, cavitation or scour on structure?					
1.2.4	Any evidence of structural distress (displaced/offset/open joints, cracking)?					
1.2.5	Any evidence of surface defects and/or material deterioration?					
1.2.6	Any evidence of seepage or leakage from water conveyance structure?					

SN	Inspection Item	Response ^a			Remarks	Condition ^b
		Y	N	NA		
1.2.7	Any other issues?					
F1	Hydro-Mechanical Component and Turbine/Pump					
F1.1	<u>Gates, Stop Logs and Bulk Heads</u>					
1.1.1	Any problems inspecting gate/stop log/bulk head (obstructed/unsafe access)?					
1.1.2	Any issues with storage of equipment (emergency stop logs, and gate leaves)?					
1.1.3	Missing or inadequate spare parts (particularly requiring regular replacement)?					
1.1.4	Any deterioration of equipment (connecting bolts, welds, surface, paint work)?					
1.1.5	Any obstructions preventing or impairing smooth operation?					
1.1.6	Any problems with the rollers (not touching tracks, inadequate lubrication)?					
1.1.7	Any problems with the seals (damage, weathering, gaps with bearing surface)?					
1.1.8	Any other issues?					
F1.2	<u>Hoists, Cranes and Operating Mechanisms</u>					
1.2.1	Any problems inspecting hoist/crane/operating mechanism?					

SN	Inspection Item	Response ^a			Remarks	Condition ^b
		Y	N	NA		
1.2.2	Missing or inadequate spare parts (particularly requiring regular replacement)?					
1.2.3	Any deterioration of equipment (connecting bolts, welds, surface, paint work?)					
1.2.4	Any wear or damage to wire cables and other moving parts?					
1.2.5	Any obstructions preventing or impairing smooth operation?					
1.2.6	Missing or inadequate provision of back-up/standby power supply?					
1.2.7	Any health and safety concerns (e.g. lack of "danger" sign during maintenance)?					
1.2.8	Any other issues?					
F1.3	<u>Valves</u>					
1.3.1	Any problems inspecting valve?					
1.3.2	Any obstructions preventing or impairing smooth operation?					
1.3.3	Any deterioration of valve and associated equipment?					
1.3.4	Any other issues?					
F1.4	<u>Trash Racks</u>					

SN	Inspection Item	Response ^a			Remarks	Condition ^b
		Y	N	NA		
1.4.1	Any problems inspecting trash rack?					
1.4.2	Problems of excessive debris and/or inadequate cleaning?					
1.4.3	Any deterioration of trash rack (rust, corrosion, and damaged blades)?					
1.4.4	Any other issues?					
F1.5	<u>Trash Rack Cleaning Machines</u>					
1.5.1	Any problems inspecting trash rack cleaning machine?					
1.5.2	Missing or inadequate spare parts (particularly requiring regular replacement)?					
1.5.3	Any deterioration of equipment (connecting bolts, welds, surface, paint work)?					
1.5.4	Any wear or damage to wire cables and other moving parts?					
1.5.5	Any obstructions preventing or impairing smooth operation?					
1.5.6	Missing or inadequate provision of back-up/standby power supply?					
1.5.7	Any health and safety concerns (e.g. lack of "danger" sign during maintenance)?					
1.5.8	Any other issues?					

SN	Inspection Item	Response ^a			Remarks	Condition ^b
		Y	N	NA		
F1.6	<u>Turbines</u>					
1.6.1	Any problems inspecting turbine?					
1.6.2	Any obstructions preventing or impairing smooth operation?					
1.6.3	Any deterioration of turbine, blades and associated equipment?					
1.6.4	Any other issues?					
F1.7	<u>Pumps</u>					
1.7.1	Any problems inspecting pump?					
1.7.2	Any obstructions preventing or impairing smooth operation?					
1.7.3	Any deterioration of pump and associated equipment?					
1.7.4	Any other issues?					
G1	Access Road					
G1.1	<u>General Condition</u>					
1.1.1	Any problems ensuring security of dam site (including gates and fencing)?					
1.1.2	Any obstructions along or at entrance to access road (temporary or long-term)?					

SN	Inspection Item	Response ^a			Remarks	Condition ^b
		Y	N	NA		
1.1.3	Any slope stability issues (road embankment or adjacent slopes)?					
1.1.4	Profuse growth of weeds/grass on or in vicinity of access road?					
1.1.5	Any drainage problems (standing water on or adjacent to road)?					
1.1.6	Any other degradation to road surface (ruts, potholes, cavities, cracking)?					
1.1.7	Any other issues?					
H1	Instrumentation					
H1.1	<u>General Condition</u>					
1.1.1	Any problems inspecting instrument (obstructed/unsafe access)?					
1.1.2	Is the instrument vulnerable to damage or theft (inadequate protection)?					
1.1.3	Any problems ensuring correct functioning of instrument (lighting, ventilation)?					
1.1.4	Any evidence of degradation to condition of instrument (rusting, vandalism)?					
1.1.5	Any evidence of instrument not working (decommissioned, broken)?					
1.1.6	Any other issues?					
I1	Other Appurtenant Structures (Flexi-Component)					

SN	Inspection Item	Response ^a			Remarks	Condition ^b
		Y	N	NA		
I1.1	<u>Bridges and Catwalks</u>					
1.1.1	Any problems inspecting bridge or catwalk (obstructed/unsafe access)?					
1.1.2	Any security issues relating to unauthorized access (e.g. for gate operation)?					
1.1.3	Are the decking, girders and supports structurally sound?					
1.1.4	Any evidence of defects or deterioration of steel, concrete or paint work?					
1.1.5	Any other issues?					
I1.2	<u>Guide Walls</u>					
1.2.1	Any problems inspecting guide wall (obstructed/unsafe access)?					
1.2.2	Any problem with drainage from behind wall (e.g. blocked weep holes)?					
1.2.3	Any evidence of scour, foundation erosion or undercutting?					
1.2.4	Any signs of differential settlement, cracking or tilting?					
1.2.5	Any other issues?					
I1.3	<u>Miscellaneous</u>					
1.3.1	Any other issues? (please specify part)					

SN	Inspection Item	Response ^a			Remarks	Condition ^b
		Y	N	NA		
J1	Emergency Preparedness					
J1.1	Emergency Action Plan					
1.1.1	Is the Emergency Action Plan (EAP) still pending, inadequate or outdated?					
1.1.2	If not, are any dam staff unaware or insufficiently conversant with the EAP?					
1.1.3	Any concerned authorities unaware or insufficiently conversant with the EAP?					
1.1.4	Do the communication directories/contact details require updating?					
1.1.5	Any problems accessing or operating the communication/warning system?					
1.1.6	Any other issues?					

^aRespond either yes (Y), no (N) or not applicable (NA).

^bCondition: Please rate the condition as either Satisfactory, Fair, Poor or Unsatisfactory as described below:

1. Satisfactory - No existing or potential dam safety deficiencies are recognized. Acceptable performance is expected under all loading conditions (static, hydrologic, seismic) in accordance with the applicable regulatory criteria or tolerable risk guidelines.
2. Fair - No existing dam safety deficiencies are recognized for normal loading conditions. Rare or extreme hydrologic and/or seismic events may result in a dam safety deficiency. Risk may be in the range to take further action.
3. Poor - A dam safety deficiency is recognized for loading conditions which may realistically occur. Remedial action is necessary. Poor may also be used when uncertainties exist as to critical analysis parameters which identify a potential dam safety deficiency. Further investigations and studies are necessary.
4. Unsatisfactory - A dam safety deficiency is recognized that requires immediate or emergency remedial action for problem resolution.

Part 2b – Consolidated Dam Health Status Report:

SN	Observations/Significant Deficiencies Noticed	Remedial Measures Suggested	Category ^a
1			
2			
3			
4			
5			

^aCategory I – deficiencies which may lead to failure; Category II – major deficiencies requiring prompt remedial measures; Category III – minor remedial measures which are rectifiable during the year

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APPENDIX C. GLOSSARY OF TERMS FOR DAM SAFETY INSPECTIONS

The purpose of this glossary is to create a common vocabulary of dam safety inspection terms for use within and among Central and State Government agencies. Terms have been included that are generic and apply to all dams, regardless of size, owner, or location.

Abutment – The part of a valley side (wall) against which a dam is built. An artificial abutment is sometimes constructed as a concrete gravity section, to take the thrust of an arch dam where there is no suitable natural abutment. The right and left abutments are those on respective sides of an observer looking downstream.

Aggregate – (1) The sand and gravel part of concrete (65 to 75% by volume), the rest being cement and water. Fine aggregate consists of particles ranging from 4 mm down to that captured on a 200-mesh screen. Coarse aggregate ranges from 4 mm up to 64 mm. (2) That which is installed to change drainage characteristics.

Air Vent – A pipe designed to let air into the outlet conduit to reduce turbulence and prevent negative pressures during the release of water. Extra air is usually necessary downstream of constrictions.

Alluvial Soils – Soils developed from transported and recently deposited material (alluvium) characterized by a weak modification (or none) of the original material by soil-forming processes.

Alluvium – A general term for all detrital material deposited or in transit by streams, including gravel, sand, silt, clay, and all variations and mixtures of these. Unless otherwise noted, alluvium is unconsolidated.

Anti-Seep Collar – A projecting collar, usually of concrete, built around the outside of a pipe, tunnel, or conduit under or through an embankment dam to lengthen the seepage path along the outer surface of the conduit.

Anti-Vortex Device – A facility placed at the entrance to a pipe conduit structure, such as a drop inlet spillway or hood inlet spillway, to

prevent air from entering the structure when the pipe is flowing full.

Appurtenant Structures or Works – Auxiliary features of a dam that are needed for the safe and proper operation of the structure. The term may include each of the following: 1) the spillway system; 2) outlet works; 3) gates and valves; 4) tunnels; 5) conduits; 6) levees; and 7) embankments.

Apron – A pad of non-erosive material designed to prevent scour holes developing at the outlet ends of culverts, outlet pipes, grade stabilization structures, and other water control devices.

Arch Dam – A dam constructed of concrete or masonry that is curved to transmit the major part of the water pressure to the abutments.

As-Built Drawings – Plans or drawings portraying the actual dimensions and conditions of a dam, dike, or levee as it was built. Field conditions and material availability during construction often need changes from the original design drawings.

ASTM – American Society for Testing Materials, an association that publishes standards and requirements for materials used in the construction industry.

Atterberg Limits – Method used to describe the consistency of fine-grained soils with varying degrees of moisture content. Depending on the amount of moisture present, fine-grained soils can be categorized by one of four states: solid, semisolid, plastic, and liquid. The Atterberg Limits define the transition between each of these states as: (1) the shrinkage limit, which is the moisture content at which the transition from solid to semisolid state takes place; the plastic limit, which

is the moisture content at which the transition from semisolid to plastic state takes place; and the liquid limit, which is the moisture content at which the transition from plastic to liquid state takes place. The Plasticity Index is the numerical difference between the liquid limit and the plastic limit of soil, which is the range of moisture content within which the soil stays plastic.

Auxiliary Spillway – Any secondary spillway that is designed to be infrequently operated, possibly in anticipation of some degree of structural damage or erosion to the spillway that would occur during operation.

Axis of Dam – The horizontal centerline of a dam in the longitudinal direction.

Backwater – The rise in water surface elevation caused by some obstruction such as a culvert, narrow bridge opening, inefficient channel, dams, buildings or fill material that limits the area through which the water shall flow. Backwater reduces the capacity of a waterway or conduit.

Barrage – While the term barrage is borrowed from the French word meaning “dam” in general, its usage in English refers to a type of low-head, dam that consists of a number of large gates that can be opened or closed to control the amount of water passing through the structure, and thus regulate and stabilize river water elevation upstream for use diverting flow for irrigation and other purposes.

Base Flow – Stream discharge derived from groundwater sources as differentiated from surface runoff. Sometimes considered to include flows from regulated lakes or reservoirs.

Beaching – The removal by wave action of a part of the upstream (reservoir) side of the embankment and the resultant deposition of this material farther down the slope. Such deposition creates a flat beach area.

Bedrock – The solid rock in place either on or beneath the surface of the earth. It may be soft, medium, or hard and have a smooth or irregular surface.

Benchmark – A marked point of known elevation from which other elevations may be established.

Bentonite – Highly plastic clay consisting of the minerals, montmorillonite, and beidellite that swell extensively wet. Often used to seal soil to reduce seepage losses.

Berm – A horizontal step or bench in the upstream or downstream face of an embankment dam. It is sometimes called a bench.

Blanket (Drainage Blanket) – A drainage layer placed directly over the foundation material, typically to control water movement to prevent soil particle migration and erosion.

Blanket Drain – A drain that extends in a horizontal direction (much like a blanket) under a large area of the downstream portion of the embankment, intercepts seepage through the embankment and the foundation, and prevents further saturation of the downstream toe. Grout Blanket – See Consolidation Grouting. Upstream Blanket – An impervious layer placed on the reservoir floor upstream of a dam. In the case of an embankment dam, the blanket may be connected to the impermeable element in the dam.

Boil – A disturbance in the surface layer of soil caused by water escaping under pressure from behind a water-retaining structure such as a dam or a levee. The boil may be accompanied by deposition of soil particles (usually granular) in the form of a cone-shaped ring (miniature volcano) around the area where the water escapes.

Borrow Area – A source of earth fill material used in the construction of embankments or other earth fill structures.

Breach – An opening or a breakthrough of a dam resulting in a release of water. A controlled breach is the deliberate, controlled removal of embankment material to release water from the reservoir at a controlled rate. An uncontrolled breach is typically caused by rapid erosion of a section of earth embankment by water or other natural, uncontrolled forces.

Breach Analysis – The determination of the uncontrolled release of water from a dam

(magnitude, duration, and location), using accepted engineering practice, to evaluate downstream hazard potential.

Breach Inundation Area – An area that would be flooded because of a dam failure.

Buttress Dam – A dam consisting of a watertight upstream face supported at intervals on the downstream side by a series of buttresses.

Cavitation – Wear on hydraulic structures where a high hydraulic gradient is present. Cavitation is caused by the abrupt change in direction and velocity of the water so the pressure at some points is reduced to the vapor pressure and vapor pockets are created. These pockets collapse with significant impact when they enter areas of higher pressure, producing high impact pressures over small areas that eventually cause pits and holes in the surface. Noises and vibrations may be easy to hear during high flows.

Channel – The part of a natural or artificial watercourse which periodically or continuously contains moving water, or which forms a connecting link between two bodies of water. It has a defined bed and banks that serve to confine the water.

Channel Stabilization – Protecting the sides and bed of a channel from erosion by controlling flow velocities and flow directions using jetties, drops, or other structures and/or by lining the channel with vegetation, riprap, concrete, or another suitable lining material.

Chimney drain – A vertical or inclined layer of permeable material in an embankment to facilitate and control drainage of the embankment fill.

Chute – A high-velocity, open channel (usually paved) for conveying water down a steep slope without erosion.

Clay – (1) Soil fraction consisting of particles less than 0.002 mm in diameter. (2) A soil texture class that is dominated by clay or at least has a larger proportion of clay than either silt or sand. Clay displays the property of cohesion when the moisture content is below the liquid limit and above the plastic limit.

Cofferdam – A temporary structure that encloses all or part of a construction area so that construction can proceed in a dry area. A “diversion cofferdam” diverts a river into a pipe, channel, or tunnel.

Cohesion – Property of unconsolidated fine-grained soil by which the particles stick together by surface forces. Cohesion is a property that lets soil be molded or rolled into shapes without crumbling.

Cohesive Soil – A sticky soil such as clay or silt that exhibits cohesion; its shear strength is about one-half of its unconfined compressive strength. When unconfined, it has considerable strength when air-dried and significant strength when saturated.

Compaction – Mechanical action that increases soil density by reducing voids.

Concrete Lift – The vertical distance between successive horizontal construction joints.

Conduit – A closed channel for conveying discharge through, under or around a dam. A pipe and a box culvert are conduits.

Consolidation Grouting (Blanket Grouting) – The injection of grout to consolidate a layer of the foundation, resulting in greater impermeability and/or strength.

Construction Joint – The interface between two successive placings or pours of concrete where a bond, not permanent separation, is intended.

Contact Grouting – Filling, with cement grout, any voids existing at the contact of two zones of different materials, i.e., between a concrete tunnel lining and the surrounding rock.

Contour – An imaginary line on the surface of the earth connecting points of the same elevation. May also be called a contour line. Topographic maps are developed to depict contour lines.

Control Section – The part of a spillway which regulates the outflows from the reservoir. A control structure limits or prevents

outflows below fixed reservoir levels and regulates releases when the reservoir rises above that level.

Core – The impervious or impervious material forming the central part of a dam or embankment. Where a dam has a core, the outer zones are usually formed of more permeable materials. Some dams are constructed entirely of a homogeneous, impermeable material with no distinct core.

Core Wall – A wall built of impervious material, usually concrete or asphaltic concrete, in the body of an embankment dam to prevent leakage.

Corrosion – The chemical attack on a metal by its environment. Corrosion is a reaction in which metal is oxidized.

Crest Length – The length of the top of a dam including the length of the spillway, powerhouse, navigation lock, and fish passages where these structures form part of the dam. If detached from a dam, these structures should not be included.

Crest of Dam – The top of a dam (See Top of Dam).

Crest Width or **Top Thickness** – The thickness or width of a dam at the level of the top of the dam. In general, the term “thickness” is used for gravity and arch dams, and “width” is used for other dams.

Crib Dam – A gravity dam built up of boxes, cribs, crossed timbers, or gabions and filled with earth or rock.

Crown of Pipe – The elevation of the top of the pipe.

Cross Section – A “cut” across any structure, such as an embankment, to depict the composition or dimensions of the structure at the point of the cross section. It may be a graph or plot of ground elevation across a stream valley or a part of it, usually along a line perpendicular to the stream or direction of flow.

Culvert – A closed conduit used for the conveyance of water under an embankment, roadway, railroad, canal or another impediment.

Cut – (1) A portion of land surface or area from which earth has been removed or will be removed by excavating. (2) The depth below the original ground surface to the excavated surface.

Cut-and-Fill – The process of earth grading by excavating part of a higher area and using the excavated material for fill to raise the surface of an adjacent lower area.

Cutoff – An impervious construction or material which reduces seepage or prevents it from passing through foundation material.

Cutoff Trench – A long, narrow excavation (keyway) constructed along the center line of a dam, dike, levee, or embankment and filled with impervious material intended to reduce seepage of water through porous strata.

Cutoff Wall – A wall of impervious material (e.g., concrete, asphaltic concrete, steel sheet piling) built into the foundation to reduce seepage under the dam.

Dam – An artificial barrier, including appurtenant works, built for impounding or diverting water. Dams may be constructed to retain normal runoff from streams and land surfaces, flood waters, water pumped from a stream or a well, and mining operations. Off-channel reservoirs may also have a dam to control the water elevation and discharge.

Dam Failure – Failures in the structures or operation of a dam which may lead to the uncontrolled release of impounded water resulting in downstream flooding affecting the life and property of the people.

Dam Incident – A problem occurring at a dam that has not degraded into a “dam failure” such as the following:

- a) Structural damage to the dam and appurtenant works;
- b) Unusual readings of instruments in the dam;
- c) Unusual seepage or leakage through the dam body;
- d) Change in the seepage or leakage regime;
- e) Boiling or artesian conditions noticed below an earth dam;
- f) Stoppage or reduction in seepage or leakage from the foundation or body of the dam

into any of the galleries, for dams with such galleries;

- g) Malfunctioning or inappropriate operation of gates;
- h) Occurrence of any flood, the peak of which exceeds the available flood discharge capacity or 70% of the approved design flood;
- i) Occurrence of a flood, which resulted in encroachment on the available freeboard, or the adopted design freeboard;
- j) Erosion in the near vicinity, up to five hundred meters, downstream of the spillway or waste weir; and
- k) Any other event that prudence suggests would have a significant unfavorable impact on dam safety.

Dam Inspection – On site examination of all components of dam and its appurtenances by one or more persons trained in this respect and includes examination of non-overflow portion, spillways, abutments, stilling basin, piers, bridge, downstream toe, drainage galleries, operation of mechanical systems (including gates and its components, drive units, cranes), interior of outlet conduits, instrumentation records and record-keeping arrangements of instruments.

Dam Owner – The Central Government or a State Government or public sector undertaking or local authority or company and any or all of such persons or organizations, who own, control, operate or maintain a specified dam.

Dam Safety – The practice of ensuring the integrity and viability of dams such that they do not present unacceptable risks to the public, property, and the environment. It requires the collective application of engineering principles and experience, and a philosophy of risk management that recognizes that a dam is a structure whose safe function is not explicitly determined by its original design and construction. It also includes all actions taken to identify or predict deficiencies and consequences related to failure and to document, publicize, and reduce, eliminate, or remediate to the extent reasonably possible, any unacceptable risks.

Dam Safety Professional – A dam safety professional is an engineer or geologist with specific experience in the design, operation, and construction of dams and appurtenant works. A dam safety professional must have specific knowledge of the dam under consideration; for example, an engineer or geologist with geotechnical or geological experience would be needed to evaluate a slope stability or soil concern. Or, an engineer with hydrologic and hydraulic experience would be required to determine spillway capacity. Dam safety professionals are qualified if they have specific experience relevant to the issues or concerns that are present at any dam. A qualified dam safety professional is required to supervise and prepare the Inspection Report for comprehensive evaluation inspections on high hazard dams.

Design Flood – The largest flood that a given project is designed to pass safely. The reservoir inflow-discharge hydrograph used to estimate the spillway discharge capacity requirements and corresponding maximum surcharge elevation in the reservoir.

Design Life – The period for which a facility is expected to perform its intended function.

Design Pool Elevation (maximum design pool elevation) – The highest water level impounded by the dam resulting from the design flood, assuming both of the following: 1) No debris blockage, unplanned restrictions, or improper operation of the spillway; 2) pre-storm water level at the level of the principal spillway.

Design Storm – The depth of precipitation that is used to calculate the volume and time distribution of runoff from a watershed that a spillway system must safely pass without jeopardizing the safety of the dam. The depth of precipitation typically ranges from fifty to one hundred percent of the probable maximum precipitation, depending upon the hazard classification.

Design Wind – The most severe wind that is possible at a particular reservoir for generating wind set-up and run-up. The determination will include the results of meteorolog-

ical studies that combine wind velocity, duration, direction and seasonal distribution characteristics in a realistic manner.

Dewatering – The removal of water from a reservoir or another area.

Dike – An embankment used to confine, divert, or control water. Often built along the banks of a river to prevent overflow of lowlands. A dike is also known as a levee.

Discharge – Usually the rate of water flow. The volume of fluid passing a point per unit time expressed as cubic meters per second, liters per minute, or millions of liters per day.

Diversion Dam – A dam built to divert water from a waterway or stream into a different watercourse.

Divide (drainage) – The boundary between watersheds.

Downstream Toe of Dam – The lowermost portion of the downstream face of a dam where the embankment intersects with the ground surface. For an embankment dam, the lowermost portion of the upstream face is the upstream toe.

Drainage Area or Watershed – An area that drains naturally to a point on a stream. For dams, the upstream area that drains into the lake, including the lake.

Drainage Layer or Blanket – A layer of permeable material in a dam to relieve pore pressure or to ease drainage of fill (see Blanket).

Drainage – The removal of excess surface water or groundwater from land by ditches or subsurface drains. Also, see Natural drainage.

Drainage Improvement – An activity within or next to a natural stream or a man-made drain primarily intended to improve the flow capacity, drainage, erosion and sedimentation control, or stability of the drainage way.

Drains – 1) Relief Wells – A vertical well or borehole, usually downstream of impervious cores, grout curtains, or cutoffs, designed to collect and direct seepage through or under a dam to reduce uplift pressure under or within

a dam. A line of such wells forms a drainage curtain. 2) A buried slotted or perforated pipe or another conduit (subsurface drain) or a ditch (open drain) for carrying off surplus groundwater or surface water.

Drawdown – The lowering of water surface level by releasing water from a reservoir.

Drop Inlet – A structure in which water enters over a horizontal lip, drops through a vertical or sloping shaft and then discharges through a conduit to the receiving waters. It is also referred to as a riser in dam construction. A drop inlet typically comprises three components: an overflow control weir, a vertical transition, and a closed discharge channel or conduit. (See Spillway.)

Embankment Dam (Fill Dam) – Any dam constructed of natural fill materials.

Earth Dam (Earthfill Dam) – An embankment dam in which more than 50% of the total volume is formed of compacted fine-grained material obtained from a borrow area.

Homogeneous Earthfill Dam – An embankment dam constructed of similar earth material throughout, except for the possible inclusion of internal drains or drainage blankets; distinguished from a zoned earthfill dam.

Rockfill Dam – An embankment dam in which more than 50% of the total volume comprises compacted or dumped natural or crushed rock.

Rolled Fill Dam – An embankment dam of earth or rock in which the material is placed in layers and compacted by using rollers or rolling equipment.

Zoned Embankment Dam – An embankment dam, which is composed of zones of selected materials having different degrees of porosity, permeability, and density.

Emergency Action Plan (EAP) – A written document prepared by the dam owner or the owner's professional engineer describing a detailed plan to prevent or lessen the effects of a failure of the dam or appurtenant structures.

Emergency Condition Level – The following three emergency condition levels are considered:

1. **BLUE** – An event has taken place that is developing slowly and needs to be monitored closely. Immediate correction action is required.
2. **ORANGE** – Dam failure is highly probable but might be avoided with corrective actions.
3. **RED** – Dam failure is imminent or ongoing.

Emergency Repairs – Any repairs that are considered temporary in nature and that are necessary to preserve the integrity of the dam and prevent a failure of the dam.

Emergency Spillway – An auxiliary spillway designed to pass a large, but infrequent, the volume of flood flow, with a crest elevation higher than the principal spillway or normal operating level.

Energy Dissipater – A device used to reduce the energy of flowing water to prevent erosion.

Erodibility – Susceptibility to erosion.

Erosion – The wearing away of the land surface by water, wind, ice, gravity, or other geological agents. The following terms are used to describe different types of water erosion: accelerated erosion – erosion much more rapid than normal or geologic erosion, primarily because of anthropogenic activities; channel erosion – an erosion process whereby the volume and velocity of flow wears away the bed and/or banks of a well-defined channel; gully erosion – an erosion process whereby runoff water accumulates in narrow channels and, over relatively short periods, removes the soil to considerable depths, ranging from 0.5 meters to as much as 30 meters; rill erosion – an erosion process in which numerous small channels only several centimeters deep are formed; occurs mainly on recently disturbed and exposed soils (see Rill); splash erosion – the spattering of small soil particles caused by the impact of raindrops on wet soils; the loosened and spat-

tered particles may or may not be subsequently removed by surface runoff; sheet erosion – the gradual removal of a fairly uniform layer of soil from the land surface by runoff water.

Face – The external surface of a structure, such as the surface of an appurtenance or a dam.

Failure Mode – A potential failure mode is a physically plausible process for dam failure resulting from an existing inadequacy or defect related to a natural foundation condition, the dam or appurtenant structures design, the construction, the materials incorporated, the operations and maintenance, or aging process, which can lead to an uncontrolled release of the reservoir.

Fetch – The-straight-line distance across a body of water subject to wind forces. The fetch is one of the factors used in calculating wave heights in a reservoir.

Filter (Filter Zone) – A band or zone of granular material that is incorporated into a dam and is graded (either naturally or by selection) to allow seepage to flow across or down the filter without causing the migration of material from zones next to the filter. Filters and associated drains within an earthen embankment permit drainage or removal of liquids to avoid saturation of the downstream toe of the embankment and/or to control seepage forces, while preventing the removal of finer sized particles. Filters associated with erosion protection on slopes of dams or in channel linings prevent the removal of finer sized particles by wave action or turbulence from beneath the larger- sized material (see blanket drain and vertical or sloping filter).

Filter Blanket – A layer of sand and/or gravel designed to prevent the movement of fine-grained soils.

Filter Fabric – See Geotextile Fabric.

Flashboards – Structural members of timber, concrete, or steel placed in channels or on the crest of a spillway to raise the reservoir water level but intended to be quickly removed, tripped, or fail in case of a flood.

Flip Bucket – An energy dissipater located at the downstream end of a spillway and shaped so that water flowing at a high velocity is deflected upwards in a trajectory away from the foundation of the spillway.

Flood or Flood Waters – A general and temporary condition of partial or complete inundation of normally dry land areas from the overflow, the unusual and rapid accumulation, or the runoff of surface waters from any source.

Flood Frequency – A statistical expression of the average time between floods equaling or exceeding a given magnitude. For example, a 100-year flood has a magnitude expected to be equaled or exceeded on the average of once every hundred years; such a flood has a 1% chance of being equaled or exceeded in any given year. Often used interchangeably with “recurrence interval.”

Flood Hydrograph – A graph showing, for a given point on a stream, the discharge, height, or another characteristic of a flood with respect to time.

Flood Peak – The highest stage or greatest discharge attained by a flood, thus peak stage or peak discharge.

Flood Routing – The determination of the attenuating effect of storage on a flood passing through a valley, channel, or reservoir.

Flood Stage – The stage at which overflow of the natural banks of a dam or a stream begins.

Flume – A constructed channel lined with erosion-resistant materials used to convey water on steep grades without erosion.

Foundation Drain – A pipe or series of pipes that collects groundwater from the foundation of a dam or the footing of structures to improve stability.

Foundation of Dam – The natural material on which the dam structure is placed.

Freeboard – Vertical distance between a specified stillwater reservoir surface elevation and the top of the dam, without camber.

French Drain – A drainage trench backfilled with a coarse, water-transmitting material; may contain a perforated pipe.

Gabion – Rectangular-shaped baskets or mattresses fabricated from wire mesh, filled with rock, and assembled to form overflow weirs, hydraulic drops, and overtopping protection for small embankment dams. Gabion baskets are stacked in a stair-stepped fashion, while mattresses are placed parallel to a slope. Gabions have advantages over loose riprap because of their modularity and rock confinement properties, thus providing erosion protection with less rock and with smaller rock sizes than loose riprap.

Gallery – a) A passageway within the body of a dam or abutment; hence the terms *grouting gallery*, *inspection-gallery*, and *drainage gallery*”; b) A long and narrow hall; hence the following terms for a power plant: *valve gallery*, *transformer gallery*, and *busbar gallery*.

Gate – A device in which a leaf or member is moved across the waterway from an external position to control or stop the flow.

Bulkhead Gate – A gate used either for temporary closure of a channel or conduit to empty it for inspection or maintenance or for closure against flowing water when the head difference is small, e.g., a diversion tunnel closure. Although a bulkhead gate is usually opened and closed under nearly balanced pressures, it nevertheless may be capable of withstanding a high-pressure differential when in the closed position.

Crest Gate (Spillway Gate) – A gate on the crest of a spillway to control overflow or reservoir water level.

Emergency Gate – A standby or reserve gate used only when the normal means of water control is not available.

Fixed Wheel Gate (Fixed Roller Gate, Fixed Axle Gate) – A gate that has wheels or rollers mounted on the end posts of the gate. The wheels bear against rails fixed inside grooves or gate guides.

Flap Gate – A gate hinged along one edge, usually either the top or bottom

edge. Examples of bottom-hinged flap gates are tilting gates and fish belly gates, so-called because of their shape in cross section. **Flood Gate** – A gate to control flood release from a reservoir.

Guard Gate (Guard Valve) – A gate or valve that operates fully open or closed. It may function as a secondary device for shutting off the flow of water in case the primary closure device becomes inoperable, but is usually operated under balanced pressure, no-flow conditions.

Outlet Gate – A gate controlling the outflow of water from a reservoir. **Radial Gate (Tainter gate)** – A gate with a curved upstream plate and radial arms hinged to piers or other supporting structures.

Regulating Gate (Regulating Valve) – A gate or valve that operates under full pressure and flow conditions to throttle and vary the rate of discharge.

Slide Gate (Sluice Gate) – A gate that can be opened or closed by sliding it in supporting guides.

Gauge – (1) A device for measuring precipitation, water level, discharge, velocity, pressure, and temperature; (2) a measure of the thickness of metal.

Geomembrane – An essentially impermeable geosynthetic composed of one or more synthetic sheets.

Geosynthetic – A planar product manufactured from a polymeric material used with soil, rock, earth, or other geotechnical engineering related material as an integral part of a man-made project, structure, or system.

Geotextile Fabric – A woven or non-woven, water-permeable synthetic material used to trap sediment particles, prevent the clogging of aggregates with fine-grained soil particles, or as a separator under road aggregate. It is also used as a filter.

Geotextile Liner – A synthetic, impermeable fabric used to seal impoundments against leaks.

Gradation – The distribution of the various sized particles that constitute sediment, soil, or another material, such as riprap.

Grade – (1) The slope of a road, a channel, or natural ground. (2) The finished surface of a canal bed, roadbed, top of the embankment, or bottom of excavation; any surface prepared to a design elevation for the support of construction, such as paving or the laying of a conduit. (3) To finish the surface of a canal bed, roadbed, top of embankment, or bottom of the excavation, or another land area to a smooth, even condition.

Gradient – (1) A change of elevation, velocity, pressure, or other characteristics per unit length. (2) Slope.

Grading – The cutting/or filling of the land surface to a desired slope or elevation.

Grassed Waterway – A natural or constructed waterway, usually broad and shallow, covered with erosion-resistant grasses and used to conduct surface water from an area safely.

Gravity Dam – A dam constructed of concrete and/or masonry that relies on its weight for stability.

Groin Area – The area at the intersection of either the upstream or downstream slope of an embankment and the valley wall or abutment.

Ground Cover (horticulture) – Low-growing, spreading plants useful for low-maintenance landscape areas.

Grout – A thin cement mortar used to fill voids, fractures, or joints in masonry, rock, sand and gravel, and other materials. As a verb, it refers to filling voids with grout. Grout is usually applied under pressure.

Grout Blanket – An area of the foundation systematically filled with a thin mortar or cement slurry to a uniform shallow depth.

Grout Cap – A concrete filled trench or pad encompassing all grout lines constructed to impede surface leakage and to provide anchorage for grout connections.

Grout Curtain (Grout Cutoff) – A narrow barrier produced by injecting grout into a vertical zone, through the embankment, into the foundation to reduce seepage under a dam; or a grout barrier injected into the foundation before the dam is constructed.

Hazard Classification – The classification of a dam that reflects the potential for loss of life and property if an uncontrolled release of the structure's contents occurs. The India classification includes high hazard, significant hazard, and low hazard.

Head – (1) The height of water above any plane of reference. (2) The energy, either kinetic or potential, possessed by each unit weight of a liquid, expressed as the vertical height through which a unit would have to fall to release the average energy possessed. Used in various compound terms, such as pressure head or velocity head.

Head Loss – Energy loss from friction, turbulent eddies, changes in velocity, elevation, or direction of flow.

Headwater – (1) The source of a stream. (2) The water upstream from a structure or point on a stream.

Height of Dam – The difference in elevation between the natural bed of the watercourse or the lowest point on the downstream toe of the dam, whichever is lower, and the effective crest of the dam.

Hydraulic Fracturing – Hydraulic fracturing in soils is a tensile separation that is created because of increased fluid pressure. Initiation and/or propagation cracks in the core sections of earthen dams because of hydraulic fracturing affect adversely structural safety of the dams.

Hydraulic Gradient – The change in total hydraulic pressure per unit distance of flow.

Hydraulic Jump – The abrupt rise in water surface that may occur in an open channel or stilling basin when water flowing at high velocity is retarded or suddenly slowed down.

Hydrograph – A graphic representation of discharge from a reservoir, or runoff from a

watershed with respect to time for a particular point.

Hydrology – The science of the behavior of water in the atmosphere, on the surface of the earth, and underground. A typical hydrologic study is undertaken to compute flow rates associated with specified floods.

Hydrostatic pressure – The pressure exerted by water at rest.

Impervious – Not allowing infiltration.

Impoundment – Generally, an artificial water storage area, such as a reservoir, pit, dug-out, or sump.

Inclinometer – An instrument, usually consisting of a metal or plastic casing inserted in a drill hole and a sensitive monitor either lowered into the casing or fixed within the casing. This device measures at different points the casing's inclination to the vertical. The system may be used to measure settlement.

Infiltration – Passage or movement of water into the soil.

Inflow Design Flood – The flood hydrograph used in the design of a dam and its appurtenant works particularly for sizing the spillway and outlet works and for determining the maximum storage, the dam height, and the freeboard requirements.

Instrumentation – An arrangement of devices installed into or near dams that provide for measurements that can be used to evaluate the structural behavior and performance parameters of the structure.

Internal Erosion – A general term used to describe all of the various erosional processes where water moves internally through or next to the soil zones of embankment dams and foundation, except for the specific process referred to as *backward erosion piping*. The term internal erosion is used in place of a variety of terms that have been used to describe various erosional processes, such as scour, suffosion, concentrated leak piping, and others.

Inundation map – A map showing areas that would be affected by flooding from releases from a dam's reservoir. The flooding

may be from either controlled or uncontrolled releases or because of a dam failure. A series of maps for a dam could show the incremental areas flooded by larger flood releases. For breach analyses, this map should also show the time to flood arrival, and maximum water-surface elevations and velocities.

In situ – In the natural or original position. With respect to dams, in situ usually refers to the existing, undisturbed earth. For example, in situ spillways are spillways constructed within the undisturbed ground, usually next to the embankment fill.

Intermittent Stream – A stream that does not maintain water in its channel throughout the year; it normally stops flowing at various times of the year.

Invert – The inside bottom of a culvert or another conduit.

Keyway – A cutoff trench dug beneath the entire length of a dam to cut through soil layers that may cause seepage and possible dam failure. A keyway may also refer to benches excavated on existing ground for the purpose of creating a stable interface between the existing ground and fill placed in an embankment.

Laminar Flow – Flow at a slow velocity in which fluid particles slide smoothly along straight lines everywhere parallel to the axis of a channel or pipe.

Large dam – A dam which is above 15 m in height, measured from the lowest portion of the general foundation area to the top of dam; or a dam between 10 m to 15 m in height and that satisfies at least one of the following, namely

- a) The length of crest is not less than 500 m;
- b) The capacity of the reservoir formed by the dam is not less than one million cubic meters;
- c) The maximum flood discharge dealt with by the dam is not less than $2000 \text{ m}^3/\text{s}$;
- d) The dam has particularly difficult foundation problems; or
- e) The dam is of unusual design.

Leakage – Uncontrolled loss of water by flow through a hole or crack. See Seepage.

Levee (Dike) – A long, low embankment usually built to protect land from flooding. If built of concrete or masonry the structure is usually referred to as a floodwall. The term “dike” is commonly used to describe embankments that block areas on a reservoir rim that are lower than the top of the main dam.

Lining – With reference to a canal, tunnel, shaft, or reservoir, a coating of asphaltic concrete, reinforced or unreinforced concrete, shotcrete, rubber or plastic to provide water tightness, prevent erosion, reduce friction, or support the periphery of the structure. May also refer to the lining, such as steel or concrete, of an outlet pipe or conduit.

Low-Level Outlet (Bottom Outlet or Sluiceway) – An opening at a low level from a reservoir used for emptying or for scouring sediment and sometimes for irrigation releases.

Low Head Dam – A dam of low height (usually less than 5 meters) made of timbers, stone, concrete or some combination thereof that extends across a stream or channel.

Maintenance – Those tasks that are recurring and are necessary to keep the dam and appurtenant structures in a sound condition and free from defect or damage that could hinder the dam’s functions as designed, including adjacent areas that also could affect the function and operation of the dam.

Masonry Dam – A dam constructed mainly of stone, brick, or concrete blocks that may or may not be joined with mortar. A dam having only a masonry facing should not be referred to as a masonry dam.

Maximum Storage Capacity – The volume, in millions of cubic meters (Mm^3), of the impoundment created by the dam at the effective crest of the dam; only water that can be stored above natural ground level or that could be released by failure of the dam is considered in assessing the storage volume; the maximum storage capacity may decrease over time because of sedimentation or increase if the reservoir is dredged.

Mulch – A natural or artificial layer of plant residue or other materials covering the land

surface which conserves moisture, holds soil in place, aids in establishing plant cover, and minimizes temperature fluctuations.

Nappe – The lower surface, or underside, of a free-falling stream of water, usually over a dam crest or weir.

Normal Storage Capacity – The volume, in millions of cubic meters (Mm^3), of the impoundment created by the dam at the lowest uncontrolled spillway crest elevation, or at the maximum elevation of the reservoir at the normal (non-flooding) operating level.

Natural Drainage – The flow patterns of stormwater run-off over the land in its pre-development state.

Non-cohesive Soil – Cohesionless soil consisting of single-grained or honeycombed particles that show low shear strength when dry, and low cohesion when wet. Sand and gravel are examples of a non-cohesive soil.

Normal Depth – Depth of flow in an open conduit during uniform flow for the given conditions.

Normal Water Level (Normal Pool Level) – For a reservoir with a fixed overflow, the lowest crest level of that overflow. For a reservoir whose outflow is controlled wholly or partly by movable gates, siphons or other means, it is the maximum level to which water may rise under normal operating conditions, exclusive of any provision for flood surcharge.

Outfall – The point, location, or structure where wastewater or drainage discharges from a pipe or open drain to a receiving body of water.

Outlet – An opening through which water can be freely discharged from a reservoir, or the point of water disposal from a stream, river, lake, tidewater, or artificial. Used to reduce the reservoir level in dams. Also, referred to as a reservoir drain.

Outlet Channel (Discharge Channel) – A waterway constructed or altered primarily to carry water from man-made structures, such as dam spillways, smaller channels, tile lines, and diversions.

Outlet works – A dam appurtenance that provides release of water (generally controlled) from a reservoir.

Overland Flow – Consists of sheet flow, shallow concentrated flow, and open channel flow. The flow of stormwater runoff across the ground surface.

Parapet Wall – A solid wall built along the top of a dam for ornament, for the safety of vehicles and pedestrians, or to prevent overtopping.

Peak Discharge (Flow) – The largest instantaneous flow from a given storm condition at a specific location.

Penstock – A pressurized pipeline or shaft between the reservoir and hydraulic machinery.

Percolation – The movement of water through the soil.

Percolation Rate – The rate, usually expressed as millimeters per hour or millimeters per day, at which water moves through the soil profile.

Perennial Stream – A stream that keeps water in its channel throughout the year.

Permeability (soil) – The quality of the soil that enables water or air to move through it. It also refers to the rate at which water moves through the soil. Usually expressed in centimeters per second, centimeters per hour, or centimeters per day.

Permeability Rate – The rate at which water will move through a saturated soil.

Permittivity – The volumetric flow rate of water per unit cross-sectional area per unit head under laminar flow conditions, in the normal direction through a geotextile.

Pervious Zone – A part of the cross section of an embankment dam comprising material of high permeability.

pH – A numerical measure of hydrogen ion activity, the neutral point being 7.0. All pH values below 7.0 are acid, and all above 7.0 are alkaline.

Phreatic Surface – The free surface of groundwater at atmospheric pressure.

Piezometer – An instrument for measuring pore water pressure within soil, rock, or concrete. The piezometric water surface is the water level in a piezometer.

Piping – The progressive development of internal erosion by seepage, appearing downstream as a hole or seam discharging water that contains soil particles. Water in the ground carries the fine soil particles away, and a series of eroded tubes or tunnels develop. These openings will grow progressively larger and can cause a dam failure.

Plunge Pool – A basin used to dissipate the energy of flowing water. Usually constructed to a specified depth and shape. The pool may be protected from erosion by various lining materials.

Pore Pressure – The interstitial pressure of water within a mass of soil, rock, or concrete. Pore pressure is a result of the height of water above the point of measurement.

Porosity – The volume of pore space in soil or rock.

Pressure Relief Pipes – Pipes used to relieve uplift or pore pressure in a dam foundation or in the dam structure.

Principal Spillway – A dam spillway constructed of a permanent material and designed to regulate and discharge water from the reservoir.

Probable Maximum Flood (PMF) – The flood that may be expected from the most severe combination of critical meteorological and hydrologic conditions that are possible in the drainage basin under study.

Probable Maximum Precipitation (PMP) – Theoretically, the greatest depth of precipitation for a given duration that is physically possible over a given size storm area at a particular geographical location during a certain time of the year.

Professional Engineer – An individual who, because of special knowledge of the: 1) mathematical and physical sciences; and 2)

principles and methods of engineering analysis and design; that are acquired by education and practical experience, is qualified to engage in the practice of engineering.

Rainfall Intensity – The rate at which rain is falling at any given instant, usually expressed in millimeters or centimeters per hour.

Reach – The smallest subdivision of the drainage system, consisting of a longitudinal section of an open channel. Also, a discrete portion of river, stream or creek. For modeling purposes, a reach is somewhat homogeneous in its physical characteristics.

Receiving Stream – The body of water into which runoff or effluent is discharged.

Recharge – Replenishment of groundwater reservoirs by infiltration and transmission from the outcrop of an aquifer or from permeable soils.

Recurrence Interval – A statistical expression of the average time between floods equaling or exceeding a given magnitude.

Relief Well – See Drains.

Repairs – Any work that may affect the integrity, safety, and operation of the dam.

Reservoir – Any impoundment or potential impoundment created by a dam. A natural or artificially created pond, lake or another space used for storage, regulation or control of water. May be either permanent or temporary.

Reservoir Area – The surface area of a reservoir when filled to controlled retention water level.

Reservoir Storage – The retention of water or delay of runoff in a reservoir either by the planned operation, as in a reservoir, or by temporary filling in the progression of a flood wave. Specific types of storage in reservoirs are defined as follows:

a) **Active storage** – The volume of the reservoir that is available for some use such as power generation, irrigation, flood control, or water supply. The bottom elevation is the minimum operating level.

- b) **Dead storage** – The storage that lies below the invert of the lowest outlet and that, therefore, cannot readily be withdrawn from the reservoir.
- c) **Flood surcharge** – The storage volume between the top of the active storage and the design water level.
- d) **Inactive storage** – The storage volume of a reservoir between the crest of the invert of the lowest outlet and the minimum operating level.
- e) **Live storage** – The sum of the active and the inactive storage.
- f) **Reservoir capacity** – The sum of the dead and live storage of the reservoir.
- g) **Surcharge** – The volume or space in a reservoir between the controlled retention water level and the maximum water level. Flood surcharge cannot be retained in the reservoir but will flow out of the reservoir until the controlled retention water level is reached.

Reservoir Surface – The surface of a reservoir at any level.

Retention – The storage of stormwater to prevent it from leaving the development site. May be temporary or permanent.

Retention Facility – A facility designed to hold a specified amount of stormwater runoff without release except by means of evaporation, infiltration or pumping. The volumes are often referred to in units of cubic meters. Dams are retention facilities.

Revetment – Facing of stone or another material, either permanent or temporary, placed along the edge of a stream to stabilize the bank and protect it from the erosive action of the stream. Also, see Riprap.

Rill – A small intermittent watercourse with steep sides, usually only a few centimeters deep.

Riprap – A layer of large stones, broken rock, boulders, or precast blocks placed in a random fashion on the upstream slope of an embankment dam, on a reservoir shore, or on the sides of a channel as a protection against waves, ice action, and flowing water. Large riprap is sometimes referred to as armoring. Revetment riprap is material graded

such that: 1) no individual piece weighs more than 50 kg; and 2) 90-100% will pass through a 300-mm sieve, 20-60% through a 150-mm sieve, and not more than 10% through a 38-mm sieve.

Riser – The inlet portions of a drop inlet spillway that extend vertically from the conduit to the water surface.

Risk analysis – A procedure to identify and quantify risks by establishing potential failure modes, providing numerical estimates of the likelihood of an event in a specified time period, and estimating the magnitude of the consequences. The risk analysis should include all potential events that would cause the unintentional release of stored water from the reservoir.

Risk Assessment – The process of deciding whether existing risks are tolerable and present risk control measures are adequate and, if not, whether alternative risk control measures are justified. Risk assessment incorporates the risk analysis and risk evaluation phases.

Rockfill Dam – See Embankment Dam.

Rock Anchor – A steel rod or cable placed in a hole drilled in rock, held in position by grout, mechanical means, or both. In principle, the same as a rock bolt, but usually the rock anchor is more than 4 meters long.

Rock Bolt – A tensioned reinforcement element consisting of a steel rod, a mechanical or grouted anchorage, and a plate and nut for tensioning or for retaining tension applied by direct pull or by torquing.

Rock Reinforcement – The placement of rock bolts, un-tensioned rock dowels, prestressed rock anchors, or wire tendons in a rock mass to reinforce and mobilize the rock's natural competency to support itself.

Rockfill Dam – An embankment dam in which more than 50% of the total volume is composed of compacted or dumped cobbles, boulders, rock fragments, or quarried rock usually larger than 3-inch size.

Roller Compacted Concrete Dam – A concrete gravity dam constructed using a dry

mix concrete transported by conventional construction equipment and compacted by rolling, usually with vibratory rollers.

Rubble Dam – A stone masonry dam in which the stones are not shaped or set in a continuous, usually horizontal, layer.

Runoff – That part of precipitation that flows from a drainage area on the land surface, in open channels, or in stormwater conveyance systems.

Saddle dam (or dike) – A subsidiary dam of any type constructed across a saddle or low point on the perimeter of a reservoir.

Sand – 1) Soil particles between 0.05 and 2.0 mm in diameter; 2) a soil textural class inclusive of all soils that are at least 70% sand and 15% or less clay.

Saturation – In soils, the point at which a soil or aquifer will no longer absorb any amount of water without losing an equal amount.

Scour or Scouring – The clearing and digging action of flowing water, especially the downward erosion caused by discharge from a dam spillway, or stream water in washing away mud and silt from the stream bed and outside bank of a curved channel.

Scarp – The steep, exposed earth surface created at the upper edge of a slide or slough, or a beached area along the upstream slope.

Sediment – Solid material (both mineral and organic) that is in suspension, is being transported, or has been moved from its site of origin by air, water, gravity, or ice and has come to rest on the earth's surface.

Sedimentation – The process that deposits soils, debris, and other materials either on the ground surfaces or in bodies of water or watercourses.

Sediment Discharge – The quantity of sediment, measured in dry weight or by volume, transported through a stream cross-section in a specified amount of time. Sediment discharge consists of both suspended load and bedload.

Sediment Pool – The reservoir space allotted to the accumulation of sediment during the life of the structure.

Seepage – The interstitial movement of water that may take place through a dam, its foundation, or its abutments. The slow percolation (or oozing) of fluid through a permeable material. A small amount of seepage will normally occur in any dam or embankment that retains water. The rate will depend on the relative permeability of the material in and under the structure, the depth of water behind the structure, and the length of the path the water must travel through or under the structure.

Seiche – An oscillating wave in a reservoir caused by a landslide into the reservoir or earthquake-induced ground accelerations or fault offset or meteorological event.

Settlement – The vertical downward movement of a structure or its foundation.

Settling Basin – An enlargement in the channel of a stream to permit the settling of debris carried in suspension.

Significant Wave Height – Average height of the one-third highest individual waves. Usually estimated from wind speed, fetch length, and wind duration

Silt – (1) Soil fraction consisting of particles between 0.002 and 0.05 mm in diameter; (2) a soil textural class indicating more than 80% silt.

Silt Fence – A barrier constructed of wood or steel supports and either natural (e.g. burlap) or synthetic fabric stretched across an area of non-concentrated flow during site development to trap and retain on-site sediment from rainfall runoff.

Sinkhole – A low section of ground that indicates subsurface settlement or particle movement, typically having clearly defined boundaries with a sharp offset.

Siphon – An inverted U-shaped pipe or conduit, filled until atmospheric pressure is sufficient to force water from a reservoir over an embankment dam and out of the other end.

Slide – The movement of a mass of earth and/or rock down a slope. In embankments and abutments, this involves the separation of a part of the slope from the surrounding material.

Slope – Degree of deviation of a surface from the horizontal, measured as a numerical ratio or percent; usually expressed as the ratio of the horizontal distance (run) to the vertical distance (rise) – e.g., 2:1. However, the preferred method for designation of slopes is to clearly identify the horizontal (H) and vertical (V) components – e.g., 2H:1V. Also note that according to international standards (Metric), the slopes are presented as the vertical or width component shown on the numerator – e.g., 1V:2H. Slope expressions in this handbook follow the common presentation of slopes – e.g., 2H:1V. Slopes can also be expressed in percent or degrees. Slopes given in percent are always expressed as (V/H) – e.g., a 2H:1V (1V:2H) slope is a 50% slope. The term gradient is also used.

Slope Protection – The protection of a slope against wave action or erosion.

Slough or Sloughing – The separation from the surrounding material and downhill movement of a small portion of the slope. Usually, a slough refers to a shallow earth slide.

Sluiceway – See Low-Level Outlet.

Soil – The unconsolidated mineral and organic material on the immediate surface of the earth that serves as a natural medium for the growth of land plants. Also see alluvial soil, Clay, Cohesive soil, Loam, Permeability (soil), Sand, Silt, Soil Horizon, Soil Profile, Subsoil, Surface soil, Topsoil.

Soil Horizon – A horizontal layer of soil that, through processes of soil formation, has developed characteristics distinct from the layers above and below.

Soil Profile – A vertical section of the ground from the surface through all horizons.

Soil Structure – The relation of particles that give the whole soil a characteristic manner of breaking – e.g., crumb, block, platy, or columnar structure.

Soil Texture – The physical structure or character of soil determined by the relative proportions of the soil components (sand, silt, and clay) of which it is composed.

Spalling – Breaking (or erosion) of small fragments from the surface of concrete masonry or stone under the action of weather or abrasive forces.

Specific Gravity – The ratio of (1) the weight in air of a given volume of soil solids at a fixed temperature to (2) the weight in air of an equal volume of distilled water at a fixed temperature.

Spillway (Spillway System) – A structure or structures that convey flow through, around, or over the dam. A spillway system typically consists of the following: 1) A principal spillway. 2) An auxiliary spillway. 3) A drawdown mechanism.

Stilling Basin – A basin constructed to dissipate the energy of fast-flowing water, e.g., from a spillway or bottom outlet, and to protect the streambed from erosion.

Stillwater Level – The elevation that a water surface would assume if all wave actions were absent.

Stoplogs – Wooden boards, timber, or steel beams or panels spanning horizontally between slots or grooves recessed in the sides of supporting piers placed on top of each other with their ends held in guides on each side of a channel or conduit providing a temporary closure versus a permanent bulkhead gate.

Storm – A storm that can be categorized as having a specific frequency for a given duration. For example, a 10-yr. frequency, 24-hr duration storm is a 24-hour storm that has a 10% probability of occurring in any one year.

Storm Frequency – The time interval between major storms of predetermined intensity and volumes of runoff – e.g., a 5-yr, 10-yr. or 20-yr storm.

Stormwater Runoff – The water derived from rains falling within a watershed or drainage area, flowing over the surface of the ground or collected in channels or conduits.

Stream – See Intermittent Stream, Perennial stream, Receiving stream.

Streambanks – The natural boundaries (not the flood boundaries) of a stream channel. Right and left banks are named facing downstream.

Structural Joint – A joint constructed where movement of a part of a structure because of temperature or moisture variations, settlement, or any other cause, would result in the harmful displacement of adjoining structural components.

Subarea/Subbasin – Portion of a watershed divided into homogenous drainage units which can be modeled for purposes of determining runoff rates. The subareas/subbasins have distinct boundaries, as defined by the topography of the area.

Subsoil – The B horizons of soils with distinct profiles. In soils with weak profile development, the subsoil can be defined as the ground below which roots do not normally grow.

Subsurface Drain – A permeable backfilled trench, usually containing stone and perforated pipe, for intercepting groundwater or seepage.

Subwatershed – A watershed subdivision of unspecified size that forms a convenient natural unit. See also Subarea.

Surface Runoff – See Runoff.

Surface Soil – The uppermost part of the soil ordinarily moved in tillage or its equivalent in an uncultivated soil. Frequently referred to as the plow layer. The surface soil is usually darker in color because of the presence of organic matter.

Suspended Solids – Solids either floating or suspended in water.

Swale – An elongated depression in the land surface that is at least seasonally wet, is usually heavily vegetated, and is usually without flowing water. Swales conduct stormwater into primary drainage channels and may provide some groundwater recharge.

Tailwater – The water surface elevation at the downstream side of a hydraulic structure such as a culvert, bridge, weir, or dam.

Time of Concentration – Is the travel time of a particle of water from the most hydraulically remote point in the contributing area to the point under study. This can be considered the sum of an overland flow time and times of travel in street gutters, storm sewers, drainage channels, and all other drainage ways.

Toe Drain – A system of pipe and/or pervious material along the downstream toe of a dam used to collect seepage from the foundation and embankment and convey it to a free outlet.

Toe of Dam – The lowermost portion of the dam embankment where the embankment intersects the ground surface. Also referred to as “downstream toe” or “upstream toe.”

Toe of Slope – The base or bottom of a slope at the point where the ground surface abruptly changes to a significantly flatter grade.

Top of Dam – The elevation of the uppermost surface of a dam excluding any parapet wall or railings.

Top Thickness (Topwidth) – The thickness or width of a dam at its top (excluding corbels or parapets). In general, the term thickness is used for gravity and arch dams, and width is used for other dams.

Topography – The representation of a part of the earth's surface showing natural and artificial features of a given locality such as rivers, streams, ditches, lakes, roads, buildings and most importantly, variations in ground elevations for the terrain of the area.

Topsoil – (1) The dark-colored surface layer, or the A-horizon, of a soil; when present it ranges in depth from a few millimeters to a meter. (2) Equivalent to the plow layer of cultivated soils. (3) Used to refer to the surface layer(s), enriched in organic matter and having textural and structural characteristics favorable for plant growth.

Trash Rack – A screen located at an intake to prevent the ingress of debris. A trash rack is typically a structure of metal or reinforced concrete bars located at the intake of a waterway, designed to prevent entrance of floating or submerged debris of a certain size and larger.

Turbidity – (1) Cloudiness of a liquid, caused by suspended solids. (2) A measure of the suspended solids in a liquid.

Underdrain – A small diameter perforated pipe that allows the bottom of an embankment, detention basin, channel or swale to drain.

Uniform Flow – A state of steady flow when the mean velocity and cross-sectional area remain constant in all sections of a reach.

Uplift – The upward pressure in the pores of a material (interstitial pressure) or on the base of a structure.

Valve – A device fitted to a pipeline or orifice in which the closure member is either rotated or moved transversely or longitudinally in the waterway to control or stop the flow.

Vegetative Stabilization – Protection of erodible or sediment producing areas with permanent seeding (producing long-term vegetative cover), short-term seeding (producing temporary vegetative cover), or sodding (producing areas covered with a turf of perennial sod-forming grass).

Vicinity Map – A map that shows the location of the dam and surrounding roads that provide access to the dam. This map should display the location of the dam in relation to major roads and streets and should include a north arrow and scale bar.

Volume of dam – The total space occupied by the materials forming the dam structure computed between abutments and from top to bottom of the dam. No deduction is made for small openings such as galleries, adits, tunnels, and operating chambers within the dam structure. Portions of power plants, locks, and spillways are included if they are needed for structural stability of the dam.

Watercourse – Any river, stream, creek, brook, branch, natural or artificial drainage channel in or into which stormwater runoff or floodwaters flow either continuously or intermittently.

Watershed – The region drained by or contributing water to a specific point that could be along a stream, lake or other stormwater facilities. Watersheds are often broken down into subareas for the purpose of hydrologic modeling.

Watershed Area – All land and water within the confines of a drainage divide. See also Watershed.

Water Table – 1) The free surface of the groundwater, or 2) the surface subject to atmospheric pressure under the ground, rising and falling with the season or from other conditions such as water withdrawal.

Wave Protection – Riprap, concrete, or other armoring on the upstream face of an embankment dam to protect against scouring or erosion because of wave action.

Wave Runup – Vertical height above the stillwater level to which water from a specific wave will run up the face of a structure or embankment.

Weephole – An opening left in a retaining wall, apron, lining, or foundation to permit drainage and reduce pressure.

Waterstop – A strip of metal, rubber, or another material used to prevent leakage through joints between adjacent sections of concrete.

Weir – A channel-spanning structure for measuring or regulating the flow of water. A type of spillway in which flow is constricted and caused to fall over a crest. Types of weirs include broad-crested weir, ogee weir, v-notch weir, sharp-crested weir, drowned weir, and submerged weir.

Wetlands – Areas that are inundated or saturated by surface water or groundwater at a frequency and duration sufficient to support, and that under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions.

Wind Setup – The vertical rise in the still-water level at the face of a structure or embankment caused by the wind stresses on the surface of the water.

Team Involved in Preparing

Guidelines for Safety Inspection of Dams

Dr. David C. Froehlich, Team Leader, DRIP Consultant

Mr. Edward E. Flint, Dam Safety Specialist, DRIP Consultant

Mr. Tom W. Kendall, Assistant Team Leader, DRIP Consultant

Shri. M. Bhaskara Reddy, Institutional Strengthening Specialist, DRIP Consultant

Central Dam Safety Organization

Central Water Commission

Vision

To remain as a premier organization with best technical and managerial expertise for providing advisory services on matters relating to dam safety.

Mission

To provide expert services to State Dam Safety Organizations, dam owners, dam operating agencies and others concerned for ensuring safe functioning of dams with a view to protect human life, property and the environment.

Values

Integrity: Act with integrity and honesty in all our actions and practices.

Commitment: Ensure good working conditions for employees and encourage professional excellence.

Transparency: Ensure clear, accurate and complete information in communications with stakeholders and take all decisions openly based on reliable information.

Quality of service: Provide state-of-the-art technical and managerial services within agreed time frame.

Quality Policy

We provide technical and managerial assistance to dam owners and State Dam Safety Organizations for proper surveillance, inspection, operation and maintenance of all dams and appurtenant works in India to ensure safe functioning of dams and protecting human life, property and the environment.

We develop and nurture competent manpower and equip ourselves with state of the art technical infrastructure to provide expert services to all stakeholders.

We continually improve our systems, processes and services to ensure satisfaction of our customers.

