SAFETY EVALUATION OF EXISTING DAMS

A WATER RESOURCES
TECHNICAL PUBLICATION

U. S. Department of the Interior
Bureau of Reclamation

UNITED STATES DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

SAFETY EVALUATION OF EXISTING DAMS

A MANUAL FOR THE SAFETY EVALUATION OF EMBANKMENT AND CONCRETE DAMS

A WATER RESOURCES TECHNICAL PUBLICATION

DENVER, COLORADO

1995

U.S. Department of the Interior
Mission Statement

As the Nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally-owned public lands and natural resources. This includes fostering sound use of our land and water resources; protecting our fish, wildlife, and biological diversity; preserving the environmental and cultural values of our national parks and historical places; and providing for the enjoyment of life through outdoor recreation. The Department assesses our energy and mineral resources and works to ensure that their development is in the best interests of all our people by encouraging stewardship and citizen participation in their care. The Department also has a major responsibility for American Indian reservation communities and for people who live in island territories under U.S. administration.

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PREFACE

Failures or near failures of several dams in the United States, such as Baldwin Hills, Lower San Fernando, and Teton, resulted in an additional emphasis being placed upon the safety of Bureau of Reclamation (Bureau) dams. In 1978, the Bureau appointed a cadre, under the guidance of Mr. Clifford J. Cortright,[1] to develop a comprehensive training program for examining and evaluating existing dams. The cadre was given the responsibility for developing a draft manual on safety evaluation of existing dams and preparing a training program for other Bureau employees.

This manual is intended to provide engineering and technical personnel at all levels of Government (Federal, State, and local) and private engineering organizations with sound, comprehensive guidelines and procedures for the examination and evaluation of public and private dams.

Following the onsite examination and completion of the Examination Report, the recommendations are analyzed by technical specialists. In addition to assessing the recommendations, the mandatory analytical reviews which are made of each dam are discussed in general terms in this manual.

Specific detailed criteria, design standards, methods of analyses, construction standards, etc., are purposely omitted from this manual. Those subjects are extensively presented in numerous text books; professional publications; and organizational policy manuals, design manuals, and technical publications. Reliable dam examinations and the associated evaluations must be made by professional personnel who have attained their qualifications by study and knowledge of these subjects. Those qualifications cannot be obtained through some kind of a recitation of "standards."

A training program has been developed to supplement this manual in training personnel responsible for dam safety.

Members of the cadre were: Messrs. E. A. Lindholm, R. O. Atkinson, D. E. Ingram, G. M. Elliott, A. E. Couture, P. G. Grey, J. C. Wadge, L. A. Johnson, D. A. Tiedemann, L. D. Cast, and E. L. McAlexander.

The final review of the first edition of the SEED Manual was accomplished by R. B. Jansen, and N. F. Parrett, and D. E. Ingram.

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CHAPTER I

GENERAL

A. INTRODUCTION

With an ever-increasing emphasis on dam safety, the need for trained examination and evaluation personnel at the Bureau of Reclamation is mandatory. This manual will provide professional personnel with a comprehensive guide to a program of dam safety examination and evaluation. Although most statements in this manual refer to organizational procedures and units within the Bureau, the principles, concepts, and general procedures are believed to be readily adaptable by any agency conducting a regulatory or in-house dam safety program for existing dams.

The general topics discussed are: (1) Bureau of Reclamation policy; (2) principles and concepts; (3) philosophy of evaluation; (4) causes of failure; (5) team makeup, training, and responsibility; (6) preparing and updating a Data Book; (7) review of design, construction, and operation; (8) onsite examinations; (9) report formats; (10) Data Book format; (11) analysis guidelines; and (12) examination checklists.

A selected bibliography on the subject of dam safety is provided in chapter X.

B. PURPOSE OF MANUAL

This manual provides a guide for use by professional personnel in performing safety evaluations of existing dams and appurtenant structures. The principles and concepts of examination and evaluation, causes of failures, and examples of adverse conditions are discussed. The manual sets forth guidelines for:

- Scope and frequency of examinations
- Team selection and responsibilities
- Preparing and updating Data Books
- Reviewing design, construction, and operations
- Making onsite examinations
- Developing conclusions and recommendations
- Preparing reports

Although this manual is devoted to the safety evaluation of existing dams, references to the Bureau's total dam safety program, including the design and construction of new dams, occur in this chapter.

C. EVOLUTION OF SAFETY OF DAMS PROGRAMS

1–1. **United States Congress.**–Tragedies such as the collapse of two non-Federal dams, the Buffalo Creek coal waste embankment in West Virginia, and the Canyon Lake Dam in South Dakota, which occurred in 1972, led to the passage of Federal dam safety legislation —the Dam Inspection Act of 1972.

The Dam Inspection Act, U.S. Congressional Public Law 92-367, signed into law August 8, 1972, authorized the Secretary of the Army, acting through the Chief of Engineers, to undertake a national program of inspection of dams. Under this authority, the Corps of Engineers has (1) compiled an inventory of Federal and non-Federal dams; (2) conducted a survey of each State and Federal agency's capabilities, practices, and regulations regarding the design, construction, operation, and maintenance of dams; (3) developed guidelines for safety inspections and evaluations of dams [1][1] ; and (4) formulated recommendations for a comprehensive national dam safety program.

1–2. **Corps of Engineers.**–The Assistant Secretary of the Army for Civil Works forwarded the report [2] on the National Program of Inspection of Dams to the Congress on November 16, 1976. The Corps of Engineers' inventory identified approximately 49,300 dams within the United States that are 25 feet or higher or have impounding capacity of at least 50 acre-feet of water. The report revealed that approximately 18 percent of such dams had never been inspected under existing State or Federal authority and that about 20,000 dams are located in areas where their failure can cause loss of life and damage to homes, buildings, public utilities, highways, and railroads. A more detailed inventory has been directed by the Presidential Statement of December 2, 1977.

At the January 1978 annual meeting of USCOLD (United States Committee on Large Dams), it was reported by the Corps of Engineers [3], that 2 weeks after the December Presidential Statement, all states were involved in the dam safety program, with 31 states indicating they had adequate laws, while the rest had none or inadequate laws.

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[1] Numbers in brackets refer to listing in the Bibliography, chapter X, section 10–1.

1-3. National Research Council Review.–The President's memorandum of April 23, 1977, directed the head of each Federal agency responsible for dams to immediately undertake a thorough review of its procedures and practices related to dam safety. The Secretary of the Interior requested that the National Research Council review the dam safety program of the Bureau of Reclamation; this was completed in late 1977 [4]. Recommendations of the National Research Council review committee to the Bureau are listed below:

- Establish an independent dam safety office responsible directly to the Commissioner of Reclamation.

- Management should ensure that adequate funds and manpower are available to accomplish all essential elements of the dam safety program.

- Extend the recently adopted policy to use independent consultants on future designs for major dams.

- Complete, on a reasonable schedule, the operating manuals for all its dams.

- Install field instrumentation, if needed, to monitor the behavior of dam structures and assist in safety evaluations.

- Obtain a thorough technical assessment by using multidisciplinary teams to perform reviews of design data, including stability analysis, construction and operating records, and thorough onsite examination of project conditions.

- Establish higher priority for the Landslide Surveillance Program.

- Give a higher priority to the Examination of Existing Structures Program, particularly for the evaluation of dams in high-risk locations. The Bureau was also directed to give a higher priority to the safety assessment of all dams located upstream from Bureau dams where failure would adversely affect the agency's dams.

- Become more aggressive in developing, testing, and where applicable, applying mathematical watershed models, and establish closer liaison with Government organizations such as the Corps of Engineers' Hydrologic Engineering Center, and with private firms that have expertise in this field.

- Obtain more complete geologic and seismological data for estimating maximum credible earthquakes and potential for surface faulting where dams are located in the regions of moderate to high seismic activity.

- Establish a more effective and comprehensive emergency preparedness program.
- Consider organizational changes at the E&R (Engineering and Research) Center to strengthen the role and responsibility of engineering geologists and geotechnical engineers.
- Implement a probabilistic or risk-analysis-based program for the purpose of ranking major Bureau dams in accordance with the hazard potential and the probability of a failure or partial failure of the dam.

The Committee recognized that the adoption of such procedures and practices depends largely upon the availability of money and manpower and upon the program priorities in the Bureau. They, therefore, stated that the next step in implementing these recommendations would be to evaluate them in the light of the objectives of dam safety, anticipated costs, and prospective benefits.

1–4. Presidential Statement.–On December 2, 1977, President Jimmy Carter announced a federal program for inspection of non-federal dams under Public Law 92-367. The objectives of the federally financed dam inspection program are to:

- "Provide technical inspection and evaluation of non-federal dams to identify actual high hazard conditions and to permit correction in a timely manner by non-federal interests."
- "Provide data for better definition of a viable national dam safety program, including the federal role."
- "Encourage and prepare the states to initiate quickly effective dam safety programs for non-federal dams."

1–5. Reclamation Safety of Dams Act of 1978 (Public Law 95-578).–On November 2, 1978, the Reclamation Safety of Dams Act became law. This act provides the Secretary of the Interior with the authority to construct, restore, operate, and maintain new or modified features at existing Federal Reclamation dams for safety of dams purposes.

1–6. Activity of Professional Groups.–Because of such dam failures as Malpasset (1959) and Baldwin Hills (1963) and the reservoir landslide which caused a flood wave to overtop Vaiont Dam (1963), the professional engineering community, concerned with the need for improved dam safety, sought more data on such incidents. Activities by professional groups are listed as follows:

- USCOLD (United States Committee on Large Dams)
  - Surveyed State practices and regulations controlling the design and construction of dams in the United States.
  - In 1970, furnished all states with a suggested model law [5] which outlined requirements for safety supervision of dams and reservoirs at all stages of design, construction, operation, maintenance, modifications, enlargement, or removal.
- ICOLD (International Commission on Large Dams)
  - In 1964, initiated a study of known dam failures and related foundation problems.
  - A 1970 study of "Risks to Third Parties from Large Dams" [6] outlines the major risk areas associated with dams and controls needed to maximize the safety of dams.
  - In 1974, published "Lessons from Dam Incidents" [7] which covered incidents prior to December 21, 1965; an effort to update this report to June 30, 1976, is underway.
- ASCE (American Society of Civil Engineers) and USCOLD.
  - In 1975, published "Lessons from Dam Incidents, USA" [8] which contains data on dam incidents up to December 31, 1972.
  - National Conferences Sponsored by the Engineering Foundation:

    (1) September 1973, Asilomar Conference on "Inspection, Maintenance, and Rehabilitation of Old Dams" [9].

    (2) August 1974, Henniker, New Hampshire, Conference on "Safety of Small Dams" [10].

    (3) September 1975, Asilomar Conference on "Responsibility and Liability of Public and Private Interest on Dams" [11].

    (4) September 1975, Asilomar Conference on "Evaluation of Dam Safety" [12].

1-7. Role of the Bureau of Reclamation.–The Reclamation Act of 1902 authorized the Secretary of the Interior to plan, build, operate, and maintain water projects designed to reclaim the arid and semiarid lands in the 17 Western States. The Secretary performs this function through the Bureau of Reclamation, which consists of the Office of the Commissioner in Washington, D.C., the E&R Center in Denver, and seven Regional Offices with their respective Project and Operation Offices. About half the Bureau's dams are operated and maintained by water-user organizations; the remaining dams are operated by Bureau personnel under the direction of the Regional Directors. However, the Bureau retains responsibility, including safety surveillance, for all its dams and can require that repairs and modifications be made, if deemed necessary.

In 1973, responsibility for the Bureau's safety of dams effort was diffused throughout the agency from the Office of the Commissioner in Washington, D.C., to the E&R Center in Denver, and the various field offices. The Bureau of Reclamation program, for the safety of its existing dams, included a number of activities related to the operation, maintenance, and safety reviews of dams under its jurisdiction. These activities are listed briefly below:

- Periodic onsite examinations.
- Dam behavior observations and reporting.
- Indepth studies of visually identified or suspected defects such as general deterioration, seepage, structural distress, spillway and outlet hydraulic behavior, and adjacent endangering geologic conditions; and comprehensive analytical studies to evaluate such items as spillway capacity, seismic stability, or surveillance instrumentation utilizing modern technology (Examination of Existing Structures Program).
- Maintenance of up-to-date SOP's (Standing Operating Procedures) for operation and maintenance of each dam and appurtenant structures.
- Awareness and reporting of hazardous conditions existing in upstream dams belonging to others that might adversely affect the safety of Bureau dams.
- Monitoring of potential landslide areas.
- Preparation of designs and supervision of construction for dam modification, rehabilitation, or replacement for safety purposes.

1–8. Bureau's Strengthened Safety of Dams Program.–

(a) ***Program.***–Some initial steps in implementing the Bureau's dam safety program were administrative and were suggested by the National Research Council's report [4], the in-house Dam Safety Review (Lange Report) [13], and the Bureau's report on Organizational Review (ORC (Organizational Review Committee)) [14].

A principal recommendation of these reports is that the ultimate responsibility for the structural safety of a dam must be assigned to a single organizational unit, and the control and authority over all factors affecting that responsibility must be maintained by that organizational unit. The dam safety program, which had previously been fragmented, was consolidated into one group directly under the ACER (Assistant Commissioner—Engineering and Research).

In accordance with the Presidential Statement of December 2, 1977, the order in which dams are examined and evaluated, is according to which have the highest hazard and create highest downstream risks.

The purpose of the SEED (Safety Evaluation of Existing Dams) Program is to comprehensively review the design, construction, and performance history of all Bureau dams, to evaluate their structural and hydraulic integrity, and to determine any need for remedial actions. The SEED Program is a part of the general strengthening of the Bureau's dam plan-design-construct-operate-maintain process.

In addition to the SEED Program, the Division of Water and Land Technical Services manages a RO&M (Review of Operation and Maintenance) program which includes onsite examinations of O&M features by Regional engineers every 3 years and with Division of Water and Land Technical Services' engineers from the E&R Center participating every 6 years.

(b) *Cadre.*–In February 1978, a safety of dams cadre consisting of soils engineers, geologists, a mechanical engineer, and earth and concrete dam design engineers was created at the E&R Center. The first part of the cadre training program was indoctrination of onsite examination and safety evaluation techniques under the guidance of Mr. Clifford J. Cortright. The instruction included an examination of available records, preparation of Data Books, onsite examinations, and preparation of reports for Navajo and Morrow Point Dams under training situations. A dam examiners' training program, using this manual as a course syllabus, was prepared by the cadre.

(c) *Formal Examination Teams.*–Each Formal Examination Team representing the disciplines of civil and mechanical engineering and geology, in addition to field examination, conducts a review of hydrology, geology, seismicity, seepage, design criteria and methods, construction, operation, instrumentation, past performance, and field conditions. The size, age, location, potential hazard, geologic setting, general condition, and recognized defects are considered in determining the frequency of dam safety examinations.

D. BUREAU OF RECLAMATION POLICY

1–9. Concept.–The design, construction, and operation of dams and appurtenant structures under the control of the Bureau shall be conducted in a manner to ensure the general public's safety from any dam failures. The timely completion of studies associated with the SEED Program is essential to fulfill the Bureau's responsibility to the public for the safe operation of its structures.

In compliance with the President's October 4, 1979 memorandum, the Secretary of the Interior, in February 1980, assigned responsibilities for implementing Department-wide dam safety program activities to Assistant Secretaries and Bureau heads.

The Commissioner of Reclamation is responsible for overall coordinating and advising on implementation and operation of the dam safety program in the Department of the Interior. Accomplishment of the Commissioner's responsibilities for coordinating, advising, and assisting other bureaus in their dam safety programs has been assigned to the ACER, Division of Dam Safety.

1–10. Individual Responsibility.–The responsibility for ensuring the structural integrity and safety of each Bureau dam belongs in part to all individuals involved in accomplishing the SEED Program. Activities of the SEED Program are coordinated by the Chief, Division of Dam Safety. The Regional Director is responsible for the accomplishment of all approved dam safety modifications.

1–11. Organizational Responsibilities for SEED Program and Safety Modifications of Dams.–

(a) *Commissioner.*–The Commissioner of Reclamation is responsible for the organizational structure and administrative directives used by the Bureau to accomplish its assigned missions.

The Commissioner established and maintains a significant mission emphasis on dam safety within the Bureau. He also coordinates and advises the program Assistant Secretaries within the Department of the Interior on implementing dam safety programs within their bureaus in accordance with the Federal Guidelines for Dam Safety and the Departmental Manual Release, 753DMI. The Commissioner makes decisions on ACER recommendations for modifications to existing dams for safety and transmits dam safety modification recommendations to the Regional Directors for implementation.

(b) *Assistant Commissioner-Engineering and Research.*–The ACER, among other duties, directs, coordinates, executes the dam safety program and evaluates the program accomplishment associated with dam and structural safety; reviews the Bureau's activities for conformance with the state-of-the-art design practices, develops dam and structural safety policies and standards to be adhered to by the Bureau and by A-E (Architectural-Engineering) firms doing contract design work for the Bureau; reviews all final designs of major structures*; conducts safety examinations and evaluations of existing dams; and coordinates and advises on the Department-wide dam safety program. The ACER will make recommendations for necessary remedial action to dams for safety to the Commissioner. As designated, provides necessary representation to the Department, OMB, Congress, and others related to the safety of dams program.

(c) *Division of Dam Safety.*–The Division serves as the principal office for planning, budgeting, directing, executing, and evaluating the Bureau's Dam Safety Program. The Division exercises final responsibility for the development of dam safety policies, technical criteria, and standards in conformance with National and Departmental policy and directives. These policies are adhered to by the Bureau and A-E contractors in safety evaluation of existing dams. The Division is also the principal office for overall coordination and advice on development and operation of the dam safety program in the Department of the Interior.

(d) *Office of Technical Review and Management Services.*–The Office is responsible for the technical reviews of the design, construction, and initial operation of Bureau dams and major structures. The Office evaluates the Bureau's technical activities; assists in developing structural safety policies, criteria, and standards; reviews feasibility reports, site selection, designs, specifica-

* A major structure is defined as one whose failure could result in loss of human life and/or major property damage.

tions, construction activities, data from monitoring systems, and special studies. The Office reviews the existing design, specifications, and construction compliance for modifications of existing dams.

(e) *Office of Liaison—Engineering and Research.*–Located in Washington, D.C., this office provides staff assistance, among other duties, to the ACER for implementing the Bureau's responsibilities in the Department of the Interior Dam Safety Program; for Washington Office interface on dam safety matters; and for dam safety support requested by the Commissioner.

(f) *Regional Directors and Project Office Managers.*–The Regional Directors may, upon request, provide engineers and geologists to participate on SEED Teams. They also supply records, information, and coordination for onsite examinations.

The Regional Directors and/or Project Office Managers are often responsible for accomplishing many of the field investigations, data collection, and instrumentation reading activities required to support the SEED Program. When the Commissioner forwards the ACER recommendations for modifications of an existing dam to the Regional Director, the Regional Director becomes responsible for the accomplishment of authorization reports, funding requests, modification designs, construction specifications, and construction of the dam safety modification.

1-12. **Organization Chart.**–The Bureau's organizational structure for the safety of dams program is shown on figure 1.

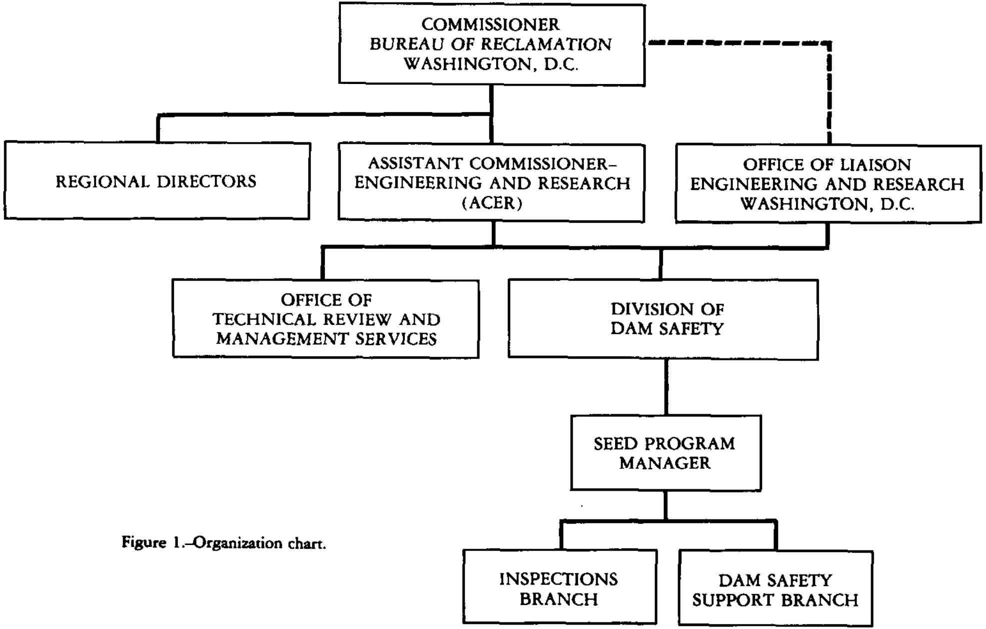

Figure 1.–Organization chart.

E. EVALUATION

Water stored behind a dam represents potential energy which creates a hazard to life and property located downstream. It is the Bureau's position that risks associated with the storage of water must be minimized. Dams must be properly designed, constructed, operated, and maintained to safely fulfill their intended function. To attain this goal, the Bureau uses a system of checks and reviews within the organization, supplemented by independent outside consultation. To further strengthen the Bureau's safety of dams policy, overall responsibility for assuring that quality is maintained in safety of dams activities is assigned to the ACER.

1–13. The Bureau's Safety Evaluation of Existing Dams Program.–The Bureau's evaluation of the safety of existing dams is accomplished by the SEED Program. The SEED Program activity flow chart is shown on figure 2.

1–14. Scope of SEED Evaluations.–The SEED Program uses the onsite examination and analysis program to appraise the safety of each Bureau dam.

The two types of onsite examination are named intermediate examinations and formal examinations. The formal examination is performed by a team of multidisciplined engineers and a geologist. The examination reviews existing records, conducts an onsite examination, and prepares an Examination Report. In addition to the usual emphasis of an examination as described in this manual, the formal examination is to be characterized by an emphasis on a fresh look at the safety of the dam and appurtenant features and a comparison of the dam against state-of-the-art standards for design, construction, performance, and safety evaluation procedures.

Intermediate examinations are conducted during the interval between formal examinations by a Team or a single Dam Safety Inspector. Both examinations (intermediate and formal) are to assess the safety of the dam. To properly assess the safety status of an existing dam, it is necessary to review the design, construction, and operation records and make an onsite examination of the dam, appurtenances, and other features which might affect the safety of the dam. The intent of analyzing all available design, construction, and performance records is to become fully acquainted with the physical features and performance history of the dam and appurtenances and identify any design, construction, performance, or operational deficiencies. After completing a review of the available records and the Data Book, the Dam Safety Inspector(s) will have the necessary information and background to perform an onsite examination of the dam

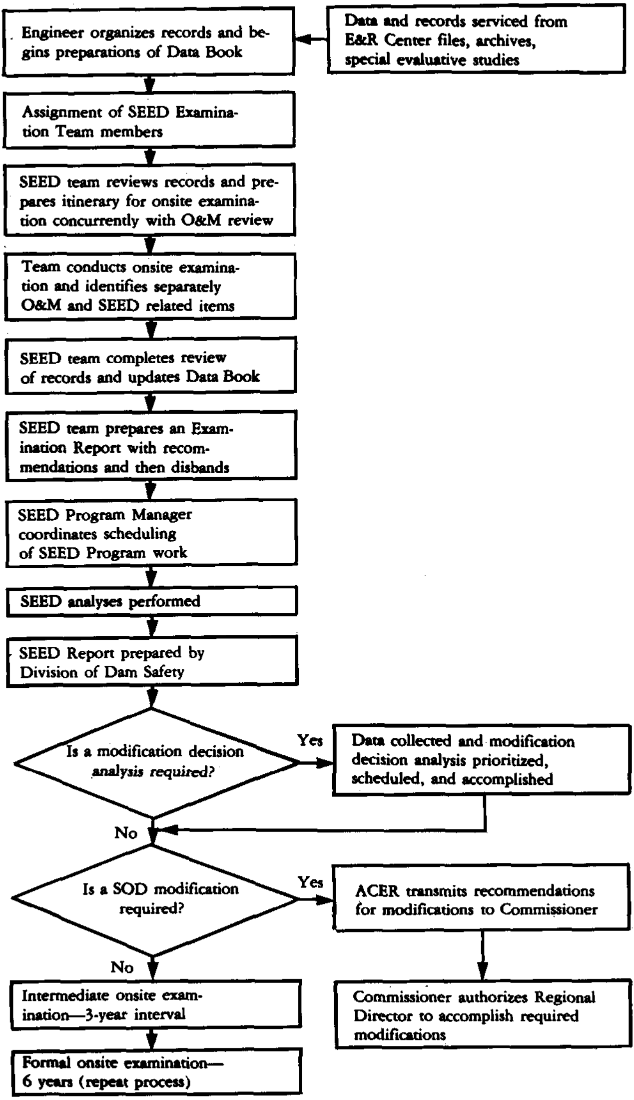

Figure 2.–Activities flow chart for SEED Program.

and other features related to dam safety. The examination is a comprehensive observation of the visible physical features of the dam and appurtenant structures.

If deficiencies which adversely affect the general safety or safe operation of the dam are identified, recommendations are made for studies of the deficiency or potential deficiency. A written report is promptly prepared which contains the results of the examination and documents the conclusions and recommendations. The recommendations in Examination Reports from both types of examinations are evaluated by technical specialists (engineers, geologists, or hydrologists). The process by which recommendations are evaluated is described in chapter VIII.

1–15. **Frequency of SEED Examinations.**–The assessment of the safety of a dam must be a continuing effort requiring the establishment of periodic safety examinations and evaluations throughout the life of the structure. Relative risk and hazard factors determined using the capacity of the reservoir; type, height, age, and general condition of the dam; present and anticipated downstream population and development; and regional seismicity are used in establishing the frequency of onsite examinations as well as determining priorities for evaluations. Engineering judgment of those familiar with the past and present performance of the dam and the experience of those operating the dam are also used to establish priorities and frequency. Frequency of onsite examinations for safety evaluations of a specific dam, once established, should be updated as the above factors change. The Bureau considers 3 years to be the maximum time interval between intermediate examinations and 6 years to be the maximum time interval between formal examinations. Based on the high priority placed on previously identified deficiencies, some dams could require intermediate examinations on a yearly basis.

CHAPTER II

PRINCIPLES AND CONCEPTS

A. PURPOSE AND PHASES OF SAFETY EVALUATIONS

2–1. **General.**–The purpose of a safety evaluation is to determine the status of a dam relative to its structural and operational safety. The evaluation should identify problems and recommend either remedial repairs, operational restrictions, and/or modifications, or analyses and studies to determine solutions to the problems.

The phases of the safety evaluation consist of reviewing the design and design data; reviewing the construction methods and materials and operational history by means of available records; examining the behavior and condition of the existing structure; making necessary analyses; developing final conclusions and recommendations; and preparing a report.

2–2. **Evaluation of Design, Construction, and Performance.**–The design of the dam and appurtenant structures should be reviewed to assess the actual performance compared to the intended performance of the structures. Engineering data and records originating during the construction period should be reviewed to determine if the structures were constructed as designed or that the necessary design revisions were made for any unusual or unanticipated conditions encountered. An onsite examination and review of available instrumentation records also should be made to assess the actual performance of the structures.

The original design and design data should be examined to determine if all appropriate loading conditions were considered. The design criteria should be reviewed to determine if changed conditions at the site have created any need for changes in the criteria such as loadings, flows, etc. Any updated design data, such as newly developed floods, regional seismicity studies, changes in material properties, etc., should be studied to determine their influence on the structure. The data should be reviewed to determine if they are correct and if the latest information has been considered.

The design should be examined to determine if the structures will safely accomplish the tasks for which they were intended, both hydraulically and structurally. The methods and procedures used in the design should be determined and compared with the latest state-of-the-art methods and criteria. If new engineering theories or improved analytical methods are available, investigation of the original design of the dam utilizing contemporary theory and analyses should be considered.

Conditions encountered during construction can have major effects on the ultimate safety of a dam. Unexpected foundation conditions, the presence of seepage, large grout "takes," indication of distress, or movements during construction are all clues to the potential development of unsafe conditions. Poor construction methods can also create latent unsafe conditions. Inadequate materials testing or control can result in the use of inferior materials or inappropriate construction methods, creating potential weaknesses in the structure that may eventually adversely affect the safety of the dam. Suitable survey control is required for construction to the lines, grades, and elevations required by the design.

Performance and operation records such as instrumentation observations and interpretations, change in operating criteria documents, Designers' Operating Criteria, maintenance reports, and other available historic records should be reviewed to determine if the structures are being operated as planned and in accordance with any design limitations. Dam tenders and operators are often able to identify problems evident only during operation activities.

The current condition of the visible features at the dam is determined by an onsite examination. The dam, appurtenant structures, and mechanical equipment should be examined to determine if they are performing as expected. Regions of distress, unexpected movements, unusual seepage or leakage, mechanical and electrical equipment malfunctions, and all other observations related to the safety of the dam should be identified and recorded. The results of the instrumentation observations and analyses may reveal or forecast dangerous conditions. Visual examination during the onsite examination can sometimes verify or dispell concerns arising from questionable instrumentation records.

2–3. Identification and Recording of Problems and Weaknesses.–The manner of identification of potential problems and weaknesses during an evaluation is complex. The records should be searched and the dam should be examined for: (1) performance that is not in accord with design predictions, (2) evidence of construction defects, (3) deviations in seepage or leakage, (4) apparent geological hazards, (5) malfunctioning mechanical and electrical equipment, and (6) indications of gradual deterioration or weakening of the structure and/or foundation.

Many times, weaknesses or deficiencies can be identified from changes in the behavior of the structure, foundation, abutments, or seepage. Knowledge of the behavior of the dam is an important tool for use in the evaluation. If surveys or instrumentation readings are lacking, they should be requested. Before the examination, the latest instrumentation results should be consulted. Historical plots of the behavior and seepage records should be available during the field examination for immediate comparison when a specific problem is suspected.

Notes should be organized in a manner covering each potential problem or defect identified during the records review and the examination, leaving nothing to memory. All data such as location, elevation, description, and quantity should be recorded. The use of a prescribed checklist for a given dam and its appurtenances can be helpful, but care must be taken to ensure that the scope of the examination is not restricted to only the listed items.

Any unusual behavior, regardless of how seemingly insignificant, should be identified and recorded because any unusual condition may be the forewarning of a newly developing unsafe condition.

An excellent method of reviewing the condition of the dam is by studying earlier photographs. Photographs taken during the examination are a permanent record of conditions for future comparisons as well as being an excellent method of notetaking. They are essential in the formulation of the Examination Report.

2–4. **Formulating and Reporting of Findings.**–Upon completion of the onsite examination of a dam, the Examination Team formulates and reports its findings in an Examination Report. When serious dam safety concerns, requiring immediate attention, are encountered during the onsite examination, the Examination Team shall upon return to the E&R Center brief the ACER Management, and Chief, Division of Dam Safety on their findings. The Examination Report documents the results of the Team findings and presents the conclusions and recommendations. The Examination Report is discussed in chapter VII. Following an analysis of recommendations contained in the Examination Report, the Division will coordinate the preparation of a SEED Report. The SEED Report presents in a single document, the management summary, SEED recommendations, analysis of recommendations, instrumentation report, and an overall safety classification of the dam.

B. REVIEW OF MODES AND CAUSES OF FAILURE

2-5. Familiarity with Modes and Causes of Failure.–The members of an Examination Team must be aware of the modes of dam failures. To understand and identify the potential failure of or weaknesses in a dam, Team members must have extensive knowledge of the causes of failure. Research and study of previous failures are required for the Team members to reinforce their engineering understanding of how and why failures occur. The Team members should use all the sources available to them for obtaining reports and descriptions of failures. The E&R Center Library, with its reference system, is an excellent source. Professional societies and magazines have published detailed reports and descriptions of dam failures. References to a number of summary-type reports and case histories are included in chapter X.

2-6. Primary Causes of Failures and Examples of Adverse Conditions.–Defects or potential defects in an embankment or concrete dam, including the foundation, may be disclosed by close examination of design and construction records, by the onsite examination, and by review of instrumentation data and past performance records.

It should be kept in mind that a full reservoir exerts high water pressures on the dam and foundation. The drainage systems must be capable of controlling the maximum seepage flows. A full reservoir also presents the potential for maximum flooding in the event of a failure.

Potential failure mechanisms and weaknesses in a dam or foundation can take many forms. Some of the more common causes of dam failures and examples of adverse conditions are discussed in detail in this section. Some of the adverse conditions that contribute to causes of failure and which often can be disclosed by visual examination are first categorized.

CATEGORIES AND CAUSES OF FAILURE

Failure	Cause
Foundation deterioration	Removal of solid and soluble materials
	Rock plucking
	Undercutting
Foundation instability	Liquefaction
	Slides
	Subsidence
	Fault movement

Failure	Cause
Defective spillways	Obstructions Broken linings Evidence of overtaxing of available capacity Faulty gates and hoists
Defective outlets	Obstructions Silt accumulations Faulty gates and hoists Gate position and location
Concrete deterioration	Alkali-aggregate reaction Freezing-thawing Leaching
Concrete dam defects	High uplift Unanticipated uplift distribution Differential displacements and deflections Overstressing
Embankment dam defects	Liquefaction potential Slope instability Excessive leakage Removal of solid and soluble materials Slope erosion
Reservoir margin defects	Perviousness Instability Inherent weaknesses of natural barriers

(a) *Foundation Deficiencies.*–These defects are associated with the quality of the foundation or with the foundation treatment. Differential settlements, slides, excessive pressures, weak seams or zones, and inadequate control of seepage are all common potential failure mechanisms within a foundation.

Visible cracks in a dam can be indicative of foundation movement. Marginal foundation stability can sometimes be identified by a thorough examination of design and construction records.

Regional subsidence caused by the extraction of ground water or hydrocarbons can cause settling of the foundation and cracking of the dam. Settlement of the dam and foundation and the resulting cracking can also occur from the collapse of foundation soils caused by loading subsequent wetting of the foundation materials. This collapse of foundation soils can occur in fine sands and silts with low densities and low natural moisture contents. The settling and subsequent cracking of embankment materials can be especially disastrous if the embankment contains soils which readily crack when deformed.

Foundation materials which have a low peak or residual shear strength or seams of weak material such as bentonite can result in sliding of the foundation and embankment. Also, seams of pervious material in the foundation which have no provisions for pressure relief can form excessive uplift pressures and cause sliding of the foundation.

Seepage through the foundation can cause piping of solid materials or the erosion of soluble materials by solutioning. This removal of foundation material forms voids which can increase until a portion of the remaining unsupported material collapses and failure of a section of the foundation occurs. Water can also cause a breakdown of some foundation materials such as shales.

Many of these weaknesses can be identified by visual examination of the foundation environs during an onsite examination. Visual evidence of piping such as sediment in the seepage water may be evident to the trained eye; whereas, the washing of soluble material into solution can be identified by chemical analyses. An increase in seepage can indicate solutioning or piping. Also, review of the design data may elicit potential adverse conditions such as the presence of water-reactive shales, dispersive clays, soluble materials, etc.

(b) *Spillway and Outlet Works Deficiencies.*–A spillway or outlet works can be defective because of hydraulic inadequacy, structural inadequacy, or operational malfunctions.

The spillway capacity may not be adequate to safely handle likely inflow floods. An updated design flood may be much larger than the one used in the original design due to improved methods of flood hydrology and availability of flood records covering longer periods. Accordingly, the existing spillway may not be adequate to safely pass the updated flood resulting in overtopping of the dam and possible failure may occur. In some cases, the outlet works are used to assist the spillway or may even be depended upon to operate alone in the routing of a design flood. If the flood expectation has increased, the outlet works may be undersized and not capable of accomplishing the functions for which it was designed. An undersized spillway or outlet works may require restricted operation of the reservoir or a modification of the structure. The latest IDF (Inflow Design Flood) estimate should be reviewed to determine if it is still valid and based on current criteria.

The history of operation of the spillway and outlet works should be reviewed to determine if their components, such as gates, valves, controls, intake and inlet structures, conveyance structures, and energy dissipators, have performed satisfactorily in the past.

Many adverse conditions such as obstructions to the flow, structural weaknesses, foundation problems, or faulty underdrains can be identified visually during an onsite examination. Structural failure in a conduit, tunnel, or other conveyance structure could obstruct the flow in the system. Gravel buildups and islands in the channel downstream from the terminal structure can restrict the tailwater, thus affecting the flow and operation of the system. Degradation of the downstream channel resulting in a lowering of the tailwater can cause improper operation of the energy dissipator. Failure of the slope protection downstream and the resulting slope failures can also affect the flow conditions.

The slides from the slopes above the inlet can block the approach channel. Slides could also damage the intake structure and associated metalwork such as gates, hoists, motors, etc.

Vegetative growth in the intake channel can reduce the flow during operation. Debris or driftwood collecting near the intake can also cause restriction of the flow. In some reservoirs, silt accumulation may cause a problem by blocking the outlet if the system is not periodically cleaned.

Stilling basins can accumulate rock, gravel, or debris. The movement of this foreign material during operation can cause faulty hydraulic operation or erosion of the surface concrete and may lead to major damage in the basin.

Cracking and movement of concrete structures can indicate distress and should be studied to determine their cause. Foundation movements, uplift, ice thrust, earthquake loads, nonfunctioning drains, changed loadings, and various other conditions could be causing the distress. In high-velocity spillways or outlet works, broken concrete or offsets in the concrete, metalwork, or paint can initiate cavitation. An onsite examination should include all portions of the system. This may require the construction of a bulkhead or cofferdam near the inlet or intake structure to unwater and fully examine the system.

All retaining walls should be examined for signs of distress. Drains should be checked to determine that they are performing as they were designed, because surface drainage that collects in the backfill behind walls can freeze and create large ice thrust stresses in the concrete.

Existing damaged areas on the flow surfaces of tunnel linings can cause areas of cavitation damage in high-velocity flow.

Spillways and outlet works controlled by gates and/or valves can only function as designed as long as the gates and valves can be operated as intended. If a spillway or outlet works cannot be operated due to faulty gates, valves, or operating equipment, the dam could be in danger of failure. Faulty operation of gates, valves, or operating equipment can result from such items as:

- Settlement or shifting of the support structure which could cause binding of gates
- Deteriorated, worn, loose, or broken parts
- Misalinement of parts
- Lack of exercise
- Lack of lubrication
- Vibration
- Improper operating procedures
- Design deficiencies
- Failure of power source
- Electrical circuit failures
- Vandalism
- Icing
- Access restrictions as might occur during flood conditions

Improper operation of the appurtenant structures can create many types of failures. Overtopping of the dam can result from improper operation of the flood storage space in the reservoir or failure to make timely releases through the spillways and outlets. Upstream slope failures on the embankment or reservoir slopes can be caused by excessive or rapid drawdown of the reservoir. Improper maintenance of the mechanical equipment can cause operational failure when use of the equipment is needed.

Hydraulic structures may have restrictions placed on them for safe operation. Many spillways and outlets require symmetrical operation to meet the design criteria. Waterhammer, excessive velocities, vibrations, etc., are items which may have to be controlled to safely operate a structure. Limits, restrictions, and instructions for safe and proper operation should be maintained at the damsite in the form of SOP's (Standing Operating Procedures) and DOC's (Designers' Operating Criteria). If these instructions are not followed, a failure condition can be created.

(c) *Inadequate Seepage Control.*–Seepage problems can occur in either concrete or embankment dams as well as through or along the foundations.

The main source of seepage within a concrete dam is through contraction joints or along unbonded construction joints or lift lines. Cracks in the mass concrete are also a potential source of seepage in the structure. Formed drains installed in the dam are designed to intercept the seepage and reduce the pressures which could develop along lifts or cracks.

Uncontrolled seepage through an embankment dam can cause the movement of soil to unprotected exits, creating voids, and leading to "piping" failures. Improper compaction; differential settlements; pervious embankment materials; or the presence of ice lenses, roots, stumps, or debris in an embankment resulting from inadequate construction control can cause excessive seepage through the embankment.

Uncontrolled seepage through the abutment or foundation of a concrete dam can form "pipes" or voids, causing the bridging of sections of the abutment and resulting in concentration of the stresses in the concrete. In the abutment or foundation of an earth dam, uncontrolled seepage can also form "pipes" or "tunnels" under the embankment. These can cause the collapse of surrounding materials which can lead to the formation of settlement cracks or ultimately to breaching of the embankment.

Uncontrolled seepage can result in excessive pore pressures in an embankment or foundation. This can cause a weakening of the soil mass and can result in springs, sand boils, abutment failures, and upstream or downstream slope failures. Excessive pore pressures can be caused during construction by placing embankment material too rapidly or by placing material which is too wet, by percolation of water through areas of pervious material in the embankment or along joints in the foundation which are connected to the reservoir, or by a rapid drawdown of the reservoir.

Hydraulic fracturing is the formation of cracks in the soil caused by the application of hydraulic pressure greater than the accompanying minor principal stress. Hydraulic fracturing of highly erodible soils, such as silts and silty sands which are not protected by filters, can result in the rapid removal of soil particles and subsequent collapse of the embankment. Drilling in embankments for investigations, installing instrumentation, or grouting has been identified as a commonly overlooked source of hydraulic fracturing. If evidence of such drilling is found in the project history, hydraulic fracturing in the embankment may have occurred at the time.

Settlement cracks caused by a compressible material in the embankment or foundation can also provide seepage paths. Shrinkage cracks caused by using highly plastic clays in the embankment can also lead to piping. Other causes of excessive seepage are animal burrows, root systems of large trees, and leakage along or through conduits in an embankment.

The adverse effects of seepage in a zoned earthfill dam are usually controlled by a filter to prevent the piping of embankment or foundation material. However, if the filter is not adequately designed or constructed to handle the volume of seepage occurring and to prevent "piping," a failure condition could exist.

Biological and chemical action can cause plugging of dam and foundation drains. If the drains remain plugged, the seepage water must seek other exit paths which can be detrimental to the safety of the dam.

Uplift pressures may exist at the base of the dam due to percolation or seepage of water along underlying foundation seams or joint systems after filling the reservoir. Measured values of uplift pressure may also indicate the effectiveness of foundation grouting and of the designed drainage system. If the uplift values are extreme or exceed the design assumptions, the stability of the dam may be reduced. If extreme or unanticipated uplift pressures or distributions are noted, additional studies may be required.

(d) *Defective or Inferior Materials.*–Defective or inferior materials used in the construction of a concrete or embankment dam can result in deterioration and possible failure of the structure.

Reactive aggregate used in a concrete dam is a major cause of concrete deterioration. If a highly reactive aggregate is used without a proper low-alkali cement, the reaction between the aggregate and cement can cause swelling of the mass concrete, creating surface cracking and deterioration. The expansion of concrete can also cause binding of gates, valves, and operating equipment, and deterioration of the concrete at metalwork supports.

Low aggregate strengths or poor bonding characteristics of cement can produce low-strength concrete which can cause cracking or areas of distress in the dam. Aggregates with high absorption characteristics are highly susceptible to freeze-thaw damage. Aggregate which has been contaminated by silt, clay, mica, coal, wood fragments, organic matters, chemical salts, or surface coatings will produce concrete of low strength and durability. Minerals in water used in the concrete mix can also prevent the production of satisfactory concrete.

Defective or inferior materials in an embankment can cause serious problems. Materials which are subject to dissolution, degradation, loss of strength, or mineralogical change are undesirable for use in an embankment.

Dissolution of soluble minerals such as gypsum can, in time, result in solution channels and subsequent piping or increased seepage. Dispersive clays in embankments are also susceptible to piping or tunneling erosion when subjected to the flow of water having a low dissolved salt content. Other soluble minerals can exhibit different characteristics, but can create similar piping conditions.

Strength loss and resulting shallow slope failures in highly plastic clays can occur near the surface of an embankment when compacted soil gradually swells, forms dessication cracks, and slides when the material is rewetted.

Low density, saturated, cohesionless soils in an embankment or foundation can experience an increase in pore pressure and loss in shear strength when subjected to earthquake-induced shear stresses. Depending on a variety of factors including material properties and inplace conditions, preearthquake stress conditions, and magnitude and duration of seismic-induced stresses, etc., the embankment or its foundation may exhibit instability, excessive vertical settlements and loss in freeboard, or cracking. Embankment dams constructed by hydraulic fill techniques are often more susceptible to earthquake-induced damage because of the potential for liquefaction under earthquake loading.

Decomposition of roots, stumps, leaves, branches, or other debris in an embankment can result in the formation of voids. These voids can allow settlement cracks or seepage paths to form, which can result in piping or excessive leakage.

(e) *Concrete and Metalwork Deterioration.*–Adverse conditions due to concrete deterioration can occur in concrete dams or appurtenant structures. The most common forms of concrete deterioration result from alkali-aggregate reaction and other chemical reactions; freeze-thaw action; leaching of the concrete; and erosion, cavitation, or damage resulting from excessive stresses.

Concrete deterioration attributable to alkali-aggregate reaction is the result of a chemical reaction between alkalies in cement and mineral constituents of concrete aggregates. Alkali-aggregate reaction can lead to deterioration well into the mass of the concrete dam. Usually, one of the early effects of the chemical reaction is the disbonding of blocks along various lift lines. The reduction of strength resulting from disbonding, combined with a buildup of hydrostatic pressure along the open lift lines, will reduce the safety factor against sliding and overturning. The actual strength of the concrete can also be reduced by chemical reaction. The condition is characterized by the following observable conditions: (1) cracking, usually of random pattern, on a fairly large scale; (2) excessive internal and overall expansion; (3) cracks that may be very large at the concrete surfaces (openings up to 1-1/2 inches) but which extend into the concrete only a distance of 6 to 8 inches; (4) gelatinous exudations and whitish amorphous deposits on the surface or within the mass of the concrete, especially in voids and adjacent to some affected pieces of aggregate; (5) peripheral zones of reactivity, alteration, or infiltration in the aggregate particles, particularly those particles containing opal and certain types of acid and intermediate volcanic rocks; and (6) chalky appearance of the freshly fractured concrete. Deterioration of concrete can also be caused by other chemical reactions such as inorganic acids, sulfates, and other salts.

Disintegration by weathering is caused mainly by the disruptive action of freezing and thawing and by expansion and contraction, under restraint, resulting from temperature variations and alternate wetting and drying. The effect of freeze-thaw action on a concrete dam is usually concentrated near the concrete surface and within exposed structural members. Parapets, cantilevers, top of dam roadway surfaces, stilling basin walls, tunnel or adit portals, and exposed decks and slabs are the most common areas affected by the freeze-thaw action. Freeze-thaw action will not normally constitute a dam safety problem except when concrete associated with the fluidway, mechanical equipment, or emergency access is affected. The effects of freeze-thaw action, like that of alkali-aggregate reaction, consist of surface deterioration and pattern cracking and can easily be identified by visual examination. It is sometimes difficult to distinguish freeze-thaw from alkali reaction except by laboratory tests.

Deterioration of concrete can also result from the soluble products in the concrete being removed by leaching.

Concrete deterioration can occur from erosion. The principal causes of erosion of concrete surfaces are:

- Cavitation
- Movement of abrasive material by flowing water
- Abrasion and impact of traffic
- Wind blasting
- Impact of flowing ice

Erosion, being a surface type of deterioration, can be easily identified by a visual examination and its cause is usually evident.

Deterioration of the concrete can be caused by unusual or extreme stresses within the structure. Once structural movement and cracking have occurred, the damage may continue from freeze-thaw action or from normal weathering of the concrete.

Overstressing of a concrete dam normally creates areas of distress and cracking that usually can be identified visually during an on-site examination. Cracking, opening of lift lines or construction joints, changes in leakage, and differential movements are all indications of potential overstressing. The overstressing may occur along the foundation because of differential or extreme foundation movements or at any location in the mass concrete of the dam where stresses are excessive. The overstressing may be due to unusual external loading conditions, temperature variations, contraction joint grouting pressures, foundation movement, or excessive uplift pressures in the foundation or along unbounded lift lines.

Deterioration of the concrete in appurtenant structures such as spillways, outlets, and critical retaining walls can be caused by cement-aggregate reaction, foundation settlement, freeze-thaw action, leaching of cement, erosion by flowing water, cavitation, or excessive stresses from external loadings. Vibration from water surges or from operation of mechanical equipment can also cause deterioration of concrete.

Deterioration due to rusting, cavitation, and/or wear can reduce the effective load carrying area of a metal part or member to the point where overstressing causes failure.

(f) *Inadequate Erosion Control.*–Inadequate protection on the upstream or downstream slopes of an embankment dam can result in erosion of the upstream face by waves or current, or gullying of the downstream face by surface runoff. Groin areas are particularly susceptible to surface erosion.

The toe of the embankment and adjacent foundation can also be subject to erosion. This can occur if the spillway and/or outlet works stilling basins are located near the dam and have inadequate slope protection around the basins and along the downstream channel.

Upstream and downstream slope protection, as well as the stilling basin and channel slope protection, is subject to deterioration. Periodic examination and repair are necessary to maintain the slope protection in satisfactory condition.

(g) *Reservoir Margin Defects.*–Events or conditions occurring within a reservoir basin that could lead to or indicate possible catastrophic failure include landslides, active faulting, seiches (seismic or landslide induced waves), shoreline erosion, and reservoir failure due to piping.

To determine the existence of any reservoir margin defects, aerial photos, regional and local geologic maps, topographic maps, and work performed by previous agencies should be reviewed. An actual field examination should then be undertaken consisting of an evaluation of known conditions and an examination for unrecognized conditions.

All reservoirs leak to some extent; however, recognizing and evaluating conditions that could lead to increased seepage are critical tasks to be performed by the Examination Team. Perviousness is a primary concern in any reservoir located in unconsolidated material and many sedimentary rocks. Specific items to be considered as percolation routes are buried channels, fault zones, joints, solution channels, and other forms of primary and secondary permeability. Indicators of excessive permeability are observed leakage, unexpected ground-water fluctuations, water boils, unexplained reservoir losses, and new springs. Percolation routes are formed by piping; solutioning of cementing agents, joint fillings, and the material itself; open joints; fracture zones including faults; bedding planes, lithologic differences, and other forms of primary and secondary permeability.

Landslides are the most prevalent form of instability affecting reservoir margins. The size of a landslide may be the primary consideration when evaluating the safety aspects. However, a small landslide in a critical location could disable a spillway or outlet works and create an unsafe condition for the dam. The evaluation of a landslide should include size, cause of failure, rate and mode of movement, type of material, age of slide, location and reservoir configuration, saturation and its sources, and movement related to reservoir fluctuations. Background data required to gain an understanding of the landslides would include a review of available pertinent memorandums, Landslide Register, and monitoring data.

Evaluation should include an appraisal of the current monitoring program and should consider new concepts of the mode of movement. A judgment should be made on the stability of the landslide and its relationship to maintaining a safe structure and restrictions on filling and lowering rates.

Shoreline erosion exists, to some extent, on old reservoirs, but is generally not a significant problem. However, wave action can undercut reservoir walls, trigger new landslides, and erode abutments.

Reservoir rims that are narrow, composed of erodible material, subject to piping, and/or unstable upon saturation, are potential areas of failure which could cause a catastrophic evacuation of the reservoir.

Items to consider in an evaluation would be a detailed geologic description and the engineering characteristics of the material, jointing, faulting, possible percolation routes, and maximum gradient between reservoir and potential exit points. Water flowing from the seepage area should be examined for suspended sediment and dissolved solids.

(h) *Inadequate Design or Construction.*–Inadequate or defective design or construction can also be causes of failure.

Incomplete or incorrect design data or criteria could result in an improperly designed structure. Failure to design for all probable loading conditions can result in an unsafe structure. Incomplete materials investigations or testing and adoption of erroneous engineering properties during design can result in the use of unsuitable material in the dam or appurtenant structures. Failure to recognize potential problems during the design stage can lead to serious accidents or failure.

Failure to control the consolidation of various zones in a zoned earthfill structure can result in differential or excessive settlements. Excessive or differential settlement can occur from improper moisture or inadequate compaction of the embankment materials.

Incomplete or inadequate foundation investigations can lead to inaccurate design assumptions and improperly designed foundation treatment. If the construction engineer did not understand or appreciate the design criteria and/or the designer was not consulted during construction, treatment to provide an adequate foundation may not have been accomplished.

Faulty construction may cause various weaknesses such as low density seams or frost zones in a dam. Changed conditions during construction which were not recognized and treated for compatibility with the design may create latent defects.

CHAPTER III

EXAMINATION TEAM

A. DISCIPLINES AND QUALIFICATIONS

An Examination Team is normally composed of civil engineers, mechanical engineers, and geologists. Engineering members of the Team should be registered professional engineers. Team members should have in-depth experience in the design, construction, and operation of dams and their appurtenant features. Appropriate Team members should have expertise in the following disciplines: hydraulics, soil and rock mechanics, structural design and slope stability analyses, mechanical design, materials properties evaluation, engineering geology, instrumentation, etc. They should also be knowledgeable of the causes and modes of dam failure.

Team members should have the desire and ability to make a comprehensive review of all data relative to the dam and make a thorough onsite examination. They should be capable of making in-depth evaluations and developing reliable conclusions. Team members should be observant, have good analytical reasoning, and not be disconcerted when confronted with voluminous detail. They should be able to concentrate on safety considerations and conditions conducive to dam failures and be alert for changed conditions. Team members should be suspicious, inquisitive, noncomplacent, methodical, and possess sound engineering judgment. They should have an independence of view and avoid quick, unfounded conclusions.

Operators and field personnel familiar with the dam and its operation should join the Team for the onsite examination. They should be capable of answering or obtaining answers to questions the Team may have concerning existing conditions and the operation of the dam.

B. ORGANIZATIONS INVOLVED

The Bureau's Examination Teams will normally be led by engineers assigned to the Division of Dam Safety. Other Team members may include Regional personnel, individual consultants, or other Division of Dam Safety staff. Other Regional and/or Project personnel and representatives from other Federal and State agencies may join the Team for the onsite examination.

Where there are suspected or known problems or defects, personnel with related expertise may also be recruited or contacted for the Team.

C. TRAINING

A program for training Team personnel has been developed for use with this manual. It is highly desirable that personnel examining dams take this training.

The training program is designed to emphasize the need for an adequate safety of dams examination and to assist the engineers and geologists in developing good review, examination, and evaluation techniques. Some of the more common causes of dam failures and examples of adverse conditions are discussed in the training program.

D. DUTIES

The Team will make a comprehensive review of all data pertinent to the safety of the dam, make an onsite examination, analyze all data and findings, update a Data Book, and prepare a written Examination Report to the Chief, Inspections Branch, stating their findings, conclusions, and recommendations relative to the safety of the dam. A detailed description of the duties is given in subsequent sections.

E. RESPONSIBILITY

The Team has the responsibility to review thoroughly all data and information, including that obtained during the onsite examination, relative to the safety of the dam. The Team has the responsibility to obtain any data it needs to conduct the review. This is normally accomplished on a routine basis by the staff of the Chief, Division of Dam Safety; however, when appropriate, memorandums will be prepared by the Team for the signature of the Chief, Division of Dam Safety, or Assistant Commissioner—Engineering and Research.

Regional and Project personnel should be advised of the itinerary and features that the Team will examine, well in advance of the onsite examination date. If special arrangements are necessary to examine specific features, these should be identified in advance. This is necessary to allow time for coordinating these reviews with their normal operating schedule.

CHAPTER IV

DATA BOOKS AND RECORDS

4–1. **General.**–Proper assessment of dam safety involves a thorough review of design, construction, and performance records prior to conducting an onsite examination. The Data Book is an unpublished document that is initially prepared by staff engineers or engineers under contract to the Division of Dam Safety. The Data Book is an abbreviated, convenient source of information summarizing all pertinent records and history related to the safety of a dam, and is prepared before the initial examination of each dam. A properly prepared Data Book should be sufficiently comprehensive so that it will not be necessary to again review in detail the source records as part of subsequent evaluations; and contain the type and quantity of records for a SEED Team to assess the structural safety of the dam. A list of references is included if additional information is needed. The Data Book should be considered a viable document which will periodically be revised and updated. This book becomes a valuable reference for Examination Teams.

4–2. **Preparing a Data Book.**–The Data Book constitutes a historical record with regard to safety of design, construction, and operation of a dam. It should contain all pertinent data relative to the safety of the dam obtained from available sources such as records and reports of design, construction, and observations and recommendations from previous evaluations and onsite examinations, checklists, Examination and SEED Reports, consultant reports, etc.

The preparer of the Data Book should provide sufficient information to help answer most questions that might arise. The preparer should extract from each record all pertinent data and information that are worthy of consideration, present these data in text form, and supplement them with their own interpretation or analysis. Complex or difficult discussions and descriptions should be copied verbatim to avoid introducing misinterpretations and thereby altering the original meaning. To supplement the text, photographs and half-size drawings should be included, but their quantity should be limited by judicious selection. Each new section or feature should begin with a new page. References which were used to obtain information that might be deemed important should be identified. A Statistical Summary should be completed for each dam and included in the Data Book. An outline for the Data Book and a sample Statistical Summary can be obtained from the Division of Dam Safety, Inspections Branch, at the E&R Center.

4–3. Updating the Data Book.–To serve its purpose as a comprehensive reference, the Data Book must be kept up to date. It should be updated when significant events occur at the dam, when updated criteria have been developed such as design earthquakes and floods, and at the time of each intermediate examination and formal examination.

Each Examination Team has the responsibility to review, update, and recommend specific additions and/or revisions to the Data Book. Any item in the Data Book that appears erroneous, unclear, or incomplete should be researched by the Team through a review of the original records or identified in recommendation by the Team.

4–4. Data Book File.–The original copies of the Data Books are retained in the Division of Dam Safety, Inspections Branch files. Microfiche copies are maintained in the E&R Center Library and in the Regional Offices.

4–5. Seed Records.–The Division of Dam Safety maintains files of records and reports required to accomplish the SEED program. Information pertaining to a dam is filed by dam name alphabetically. The Inspections Branch maintains files for Data Books and preliminary evaluations required to support Examination Teams. The SEED Program Manager maintains files on engineering and geology studies accomplished to evaluate the safety of dams. Upon completion of an analysis, the technical specialist who was responsible for performing the analysis or monitoring the contract accomplishment will prepare a brief synopsis which includes data summaries, assumptions and procedures used in the analysis, findings, conclusions and recommendations, if any. When the analysis and its results are concurred in, copies of the synopsis are forwarded to the SEED file on the subject dam and to the Inspections Branch for later incorporation into the Data Book on that dam.

CHAPTER V

EVALUATION OF DESIGN, CONSTRUCTION, AND OPERATION

5–1. Scope of Data Review.–This portion of the evaluation is devoted to reviewing, analyzing, and evaluating all available data relative to design, construction, and operation of the dam and appurtenant features. With this background, the Examination Team will be fully acquainted with the dam and its history of operation and maintenance so that they may effectively examine and evaluate its capability to perform as expected in the future.

Previous examination reports of the RO&M (Review of Operation and Maintenance), formerly ROM (Review of Maintenance), Program and reports of the SEED (Safety Evaluation of Existing Dams) Program provide a valuable source of information relating to the operational history and recent condition of the dam. The recommendations arising from these programs reveal the the history, progress, and status of repair or modification of the dams.

Any potentially adverse effect of upstream and downstream dams on the safety of a Bureau dam should be determined.

During the evaluation process, the adequacy of the dam and its appurtenances to perform their required functions should be determined. Should any inadequacy be identified, it should be described and supported by relevant data, engineering reasoning, and analyses. Experts in related fields should be consulted to advise and assist in the preparation of supporting statements and analyses, findings, and conclusions.

Throughout the evaluation process, the Examination Team should be cognizant of the responsibility for preparing a Data Book or updating an existing Data Book with new information regarding changed conditions, as discussed in chapter IV.

A comprehensive outline of considerations for making safety evaluations is provided in appendix A.

5–2. Availability and Source of Data.–During the preliminary assessment prior to the initial evaluation of a dam, all investigation, design, and construction records as described in section 5–3 are to be retrieved for use by the Team. The list of records is not necessarily considered complete, but rather should be representative of what might be available. A recently constructed dam will have numerous records available, whereas an older dam, particularly one constructed during or before the early 1900's, may have very few records.

If the dam to be evaluated was designed and constructed by the Bureau of Reclamation, nearly all available records will be found in the Bureau archives. Design section personnel who might have been involved should be questioned as to the existence of any records or information that have been filed in the archives. Regional and Project Offices should also be contacted to obtain any operational and maintenance records or related data which might be useful.

Design and construction records for an old dam can be very limited in quantity or even nonexistent. In this situation, the Examination Team must search technical publications for information and possibly recommend that field data be collected.

For dams designed and constructed by other State or Federal agencies, the appropriate agency or office should be contacted to obtain the necessary records. Again, missing or nonexisting data may need to be obtained by the agency at the site.

The types, formats, and purposes of reports, records, and data vary with dam owners and their agents who prepared them. However, patterns do exist for the progressive phases of project development from planning to operation. Those patterns will resemble, to some degree, the system used by the Bureau as described in section 5–3 and the review process for the records of other dam owners will be similar to that described in section 5–4.

5–3. Description of Bureau Records.–The following paragraphs describe and discuss Bureau reports and records which might be available for review at the E&R Center.

(a) *Technical Record of Design and Construction.*–This document is a publication of the Bureau of Reclamation which has been produced for many Bureau dams. Copies of this document, if available, can be obtained through the Office of Technical Review and Management Services or the Library at the E&R Center. This record contains general planning, historical information, a description of the features, summary of costs, geology, design aspects of the various features and their components, contract administration, and construction operations. The design aspects include a discussion of the studies performed in determining the final design, criteria and assumptions, structural and hydraulic design, design flood studies, seismicity, foundation treatment, river diversion, and mechanical design. Construction methods and operations utilized by the Contractor and problems encountered during construction are also discussed in detail.

(b) *Construction Considerations.*–These documents, formerly entitled "Design Considerations," are written for each major specifications and where new or unusual methods of construction are required, or where unusual safety or performance considerations must be met. They are written for construction personnel to outline the general design concepts, to alert them to actual field conditions which vary from those anticipated by the designers, and to suggest actions required to ensure that the specifications are complied with to meet design concepts. They call attention to environmental, geologic, foundation, maximum construction floods, and ground-water information which influenced the design; also critical settings or installation tolerances, and methods of construction are given. The Design Considerations and Construction Considerations are available in the E&R Center Library.

(c) *Design Summary.*–Publication of this document began for all new designs after 1978. It is prepared by the design groups within the Design Divisions at the E&R Center. A Design Summary contains: A statement of purpose for the project; a description and location of the project; a chronology of events; a discussion of the selection of site and structure type; cost estimates; design and construction schedule, including staff day estimates; design data; geology; seismology; technical design memorandums on every major component of the project; all decision memorandums; Construction Considerations; and references. Design Summaries are kept on file in the Library and in the Concrete and Embankment Dam Branches at the E&R Center.

(d) *Laboratory Reports.*–These reports by laboratory engineers contain results of studies performed at the request of design engineers. Reports or memorandums can be obtained from the Bureau's publications distribution office, laboratory offices, Library, or Archives.

(e) *Stress Model Reports.*–Although stress model studies were not performed for most Bureau dams, the existence of such studies should be determined. If available, these reports can be found in the Bureau's publications distribution office, design offices, Library, or Archives.

(f) *Geology Reports.*–Preconstruction and final geologic reports and aerial photographs are generally available in the Division of Geology, Library, or Archives. Personnel of the Division of Geology also should be contacted concerning the existence of other geology reports.

The Water O&M Branch maintains a Landslide Surveillance Register which provides data on such items as date of last movement, volume, monitoring, date last examined, and other details.

(g) *Site Seismicity Reports.*–For recent dams, seismic data used in design can be found in the Technical Record of Design and Construction, the Final Design Report, or memorandums from the Division of Geology.

(h) *Historic Seismicity Plots.*–Records of reported earthquake events are tabulated on magnetic tape and updated by the National Geophysical and Solar–Terrestrial Data Center of NOAA (National Oceanic and Atmospheric Administration) in Boulder, Colorado. Computer plotted maps of these events are available from NEIS (National Earthquake Information Service). While this data is in an unrefined form, it does provide indication of historic activity in any given dam vicinity.

(i) *Plans and Specifications.*–Plans and specifications for Bureau dams are filed in the E&R Center Library. This record will provide the original design concept. Later plans and specifications involving modifications to the project must also be reviewed. Care must be exercised to ensure that all plans and specifications involved in the project have been retrieved. Construction and as-built drawings should also be reviewed.

(j) *Final Design Report.*–This report contains descriptions of the main features; the conditions, assumptions, and procedures of design, including hydraulic requirements, allowable stresses, and stability factors, etc.; the principal alternatives considered and the reasons for the selection of the adopted design; design changes and the reasons therefor; a brief treatment of the site geology with emphasis on special geological problems; methods and results of pertinent analyses and tests; a bibliography of pertinent published or unpublished documents; and illustrations as are available. Final Design Reports are kept on file in the E&R Center Library.

(k) *Final Construction Report.*–This report is prepared in the Bureau's Project Construction Offices at the conclusion of construction. This record covers the complete history of construction. Construction problems and their solutions are covered in much more detail in this report than in the Technical Record of Design and Construction. Many photographs of construction operations are included, which may be very useful. Details can be found on investigations, geology, construction materials, contract administration, construction operations, instrumentations, grouting operations, embankment construction, concrete construction and control, and installation of mechanical equipment. A copy of the Final Construction Report can be obtained from the Bureau Archives by request from the E&R Center Library.

(l) *Final Grouting Report.*–This report contains detailed information on foundation grouting procedures and results. Drilling and grout-take quantities for each hole are listed and unusually high grout takes are discussed. Problems encountered during drilling and grouting are also discussed. This report can be obtained from the Bureau Archives by request from the E&R Center Library.

(m) *Construction Progress Report.*–The following reports are typical of the reports customarily prepared which discuss the contruction activity. These reports are available through the Bureau's Correspondence and Records Unit at the E&R Center.

(1) Weekly Progress Reports–The Bureau may require the Construction Engineer to submit a weekly report to the E&R Center throughout the duration of construction activity. This report covers the progress made during the previous week for construction activity such as excavation, concrete production and placement, embankment, mechanical installations, etc. Photographs of selected features of construction are generally included in the report.

(2) Drilling and Grouting Operations Report (L-10)–Each month the Construction Engineer submits a detailed summary of drilling and grouting operations that were performed during the month. For each type of drill hole, the quantities of drill length in feet and grout take in sacks of cement are listed. Any unusually high grout take is discussed.

(3) Technical Installations Report (L-21)–In addition to covering the details of instrument installation, this report provides results from installed instruments taken during construction and reservoir filling and operation. Any unusual problems which have been observed should be found in this report in addition to other reports. Photographs of instrument installations are generally included at the end of these reports.

(4) Monthly Construction Activity Reports (L-29)–This report covers construction activity and progress during each month but does not generally provide as much detail as can be found in the weekly report. A drawing or bar chart which depicts construction progress is generally provided.

(5) Daily Inspectors' Report–The inspectors' reports provide detailed information on daily construction activity which includes progress made and problems encountered.

(n) *Travel Reports.*–Throughout construction, numerous travel reports are prepared by designers and construction liaison personnel concerning visits to the construction site. Reasons for visits to the site might include a review of construction activity, construction problems, and other pertinent information. Travel reports are available in the Correspondence and Records Unit.

(o) *Correspondence Files.*–Official files of correspondence are available in the Correspondence and Records Unit. These files should be retrieved, reviewed, and retained for reference throughout the review process.

(p) *Operation and Maintenance Records and Past Examination Reports.*–Past examination reports of the RO&M Program provide detailed descriptions of conditions existing at that time, recommendations for repair or modification of a feature, and photographs of all important aspects of the project. The photographs provide an excellent comparison of changing conditions in relation to time. The reports describe reasons for repairs and modifications which should be made and evaluations of previous recommendations which have not been accomplished. These reports are filed in the Division of Water and Land Technical Services.

Reports and memorandums of the EES (Examination of Existing Structures) Program provide information pertaining to analytical studies for the hydrologic and seismic adequacy of the dam and appurtenances. These records are found in the general correspondence files or in the files of the particular organizational segment involved.

(q) *DOC (Designers' Operating Criteria).*–The DOC, if available, can be obtained through the Office of Technical Review and Management Services or the Concrete or Embankment Dams Branches, for Bureau dams. This document is prepared by the designers for the operation of the dam and the appurtenant features. It contains criteria to be followed in operating the dam and any restrictions which might have been imposed on the operating features.

(r) *SOP (Standing Operating Procedures).*–The SOP is prepared by the Regional Office for use by the operating personnel and can be obtained through the Division of Water and Land Technical Services. The SOP contains many of the procedures required to maintain and operate equipment at the dam, a communications directory, notification procedures to be utilized in case of an emergency, and an Emergency Preparedness Plan. The SOP's are reviewed yearly and updated as required. This document should clearly define the operating procedures for all anticipated situations including emergencies.

(s) *Reservoir Operation Records.*–Records of reservoir operation, beginning with the initial reservoir filling, are available for all Bureau reservoirs. These records contain data for reservoir elevation, inflow, and releases. These records are usually filed in the Division of Planning Technical Services at the Bureau's E&R Center, but may also be obtained from the appropriate Regional Office.

(t) *Data Book.*–Data Books are on file in the Division of Dam Safety, Inspections Branch Office. These data provide a valuable source of information for future teams. In using the Data Book, the Team should recognize that the information may be incomplete and that additional review of the sources records may be required. Microfiche copies of the Data Books are also on file in the E&R Center Library and in the responsible Regional Office.

(u) *Safety of Dams Data Base.*–A Safety of Dams Data Base is maintained in accessible storage in the computer at the E&R Center. The Data Base contains selected structural and dam safety information on each dam in the SEED program. Short narratives on suspected and known deficiencies are included in the Data Base. The safety of dams Data Base should be queried for information during the review of records, and comments for changes necessary to bring the Data Base information up to date should be provided to the Chief, Inspections Branch before work on the Examination Report is complete.

5–4. Reviewing the Records.–

(a) *Preconstruction Phase.*–Records during the preconstruction phase contain information on materials investigations, preconstruction geology, photographs, and other data. With these records, the Team can evaluate the quality of the data obtained, the validity of their interpretation and use by the designer and geologist at the feasibility and specifications design stages. (These records are located in the Bureau Archives or in the Divisions of Dam and Waterway Design and Geology.)

(b) *Design Phase.*–Numerous design documents including Construction Considerations, Design Summaries, Final Design Reports, and for selected major projects–Technical Records of

Design and Construction are filed as indicated in section 5-3 or in the respective design sections according to the structural feature. A review of these records will provide essential information on the type and quality of data available at the time of design, the criteria that were established, the decisions that were made which might have influenced the design, and the final construction plans and specifications which governed the construction of the structure.

Copies of plans and specifications are on file in the E&R Center Library. Any other plans and specifications for alterations, repairs, or modifications to the dam or appurtenances should also be reviewed. With these data, the Team can evaluate the suitability of the design and the construction specifications to the site characteristics.

A Technical Record of Design and Construction provides background material on design criteria, assumptions, analyses, loading conditions, and results of analyses for dams and their appurtenant structures. To supplement this record, the Team should consult other documents such as Final Design Reports, Construction Considerations, Design Summaries, documentation of design decisions and design calculations, stress and stability analyses reports, flood routing studies, hydraulic model studies, laboratory tests, site seismicity reports, and DOC's.

When reviewing the geology records, particular consideration should be given shear zones, faults, open fractures, seams, joints, fissures, caverns, landslides, variability of formations, compressible or liquefiable materials, and weak bedding planes. Using this information, a determination should be made as to the continued suitability of the damsite. Records of mineral, hydrocarbon, and ground-water extractions, including locations, production horizons, accumulated production, and current rate of production should be examined. Subsidence surveys, if available, should be reviewed.

Based on the background knowledge gained from these reports, an assessment of the adequacy of the foundation and its treatment should be made.

Materials investigation reports should be reviewed to determine the origin and physical properties of the concrete aggregate, embankment materials, and other construction materials. With this information, the Team can evaluate the durability and strength characteristics of the materials relative to their function in the structures. Particular attention should be given to the resistance properties of the materials with respect to breakdown, freeze-thaw, chemical attack, alkali-aggregate reaction, sulfate resistance, and other factors.

The IDF (inflow design flood) is usually described in Technical Records of Design or in memorandums prepared by hydrologists in the Hydrology Branch, Division of Planning Technical Services. The flood used during design might be outdated. If so, the Team should secure updated design flood and flood-routing studies in order to assess the adequacy of the spillway capacity. In cases where the old IDF for a Bureau dam has been judged to be inadequate or nonexistent, a new storm and flood study should be scheduled by the SEED Program Manager and performed by the Hydrology Branch, Division of Planning Technical Services, or the Regional Hydrology Branch. The adequacy of the spillways and flood-related appurtenances can then be assessed after routing the officially updated floods.

In considering the safety of a dam during an emergency situation, the release capability for emptying the reservoir can be very critical. This capability might have been determined during design. However, if no record can be found, the Examination Team should determine the release capability in concert with the appropriate organizational unit.

Dams can fail or be severely damaged by ground motions from earthquakes. Methods of determining the response of a structure to a design earthquake are becoming more realistic and dependable. Therefore, design earthquakes developed by current technology should be used. The site seismicity data that were considered during design are contained in design reports and memorandums. Updated data are available in the Correspondence and Records Unit files or in the files of the Division of Dam Safety at the E&R Center. The Examination Team should review the seismic data and, if those used during design are outdated, the Team should secure an updated site seismicity study from the Division of Geology and a stress and stability reanalysis of the dam using current technology.

(c) *Construction Phase.*–Latent defects from poor construction may appear later and adversely affect the safety of a dam. By analyzing the available reports, the reviewer can sometimes determine how a particular construction technique might have contributed to a current condition.

Construction records are generally quite numerous for recently constructed dams. Throughout the construction period for a Bureau dam, monthly construction activity reports are prepared by the Project Construction Office. In addition, weekly construction activity, technical installation, and grouting reports covering construction activity in detail might have been prepared by the Construction Engineer. Construction correspondence, in addition to the above reports, provide great detail in all activities of construction, including unusual or unexpected conditions encountered and remedial measures adopted.

Adequate foundation preparation and treatment are essential to the ultimate structural integrity of a dam. Construction records and construction geology reports are useful in evaluating the adequacy of the foundation. The acceptance of the foundation is generally supported by a memorandum that has been prepared and signed by an experienced engineer. Foundation grouting records provide data on grouting, such as the location, orientation, depth, and grout take for each hole.

Photographs taken prior to and during construction provide an excellent visual interpretation of the project from inception through completion. Problems described in the records are often documented by the photographs and their relationship or interaction with adjacent structural features can be visually evaluated. Geological features which affect the design can also be seen in the photographs. A comprehensive analysis should be made of all photographs to identify any abnormality or discrepancy which might have been overlooked during the design and construction stages but could affect the long-term operational safety of a structure.

(d) *Postconstruction Phase.*–Beginning with the initial filling of the reservoir, operation records are maintained to provide a complete operational history of the reservoir, spillway, and outlet works. These records contain the reservoir elevation, inflow, and releases for each day. From a scanning of these data, maximum and/or usual stages of operation can be identified. The operation of appurtentant structures should be compared to DOC and SOP instructions.

Once the reservoir has been filled, the possibility of landslides is increased and ever present, particularly because of a fluctuating water surface. The potential for occurrence and the ultimate consequence of a landslide failure should be determined.

The performance of the dam and appurtenances should be determined by studying the correspondence files, special reports, and instrumentation records. A discrepancy in the operation of a structural component should be identified and studied to ascertain its effect on the overall safety of the dam.

By examining the correspondence files, the Team can become acquainted with the preconstruction activities, design data, problems during construction, modifications to the original design, modifications made during manufacture, installation and operation of any mechanical equipment, and postconstruction and maintenance problems. Any correspondence which has been used as background material in the Data Book, Examination Report, or SEED Report, should be listed as a reference, if significant.

Included in this records examinations should be a review of all instrumentation records which would include layout drawings, observation program, scheduling, and plots of results. The performance of all structures should be compared with the design criteria and assumptions to verify that the structures are behaving or performing as anticipated.

Significant repairs and modifications should be especially noted. If possible, reasons and background information should be provided for each repair and modification. Modifications required during construction can be identified in Records of Construction, Final Construction Reports, as-built drawings, and correspondence. During the operational stage, repairs and modifications, either completed or anticipated, are described in the correspondence files or past examination reports.

Site security is sometimes needed to discourage sabotage, vandalism, and destruction by visitors and to deter trespass into critical areas. Although no security system can be considered 100 percent effective, it does deter a large percentage of people. These systems include fencing, photoelectric warning devices, or television monitoring. Control devices should be housed in a locked cabinet, room, or structure, or protected by a warning or detection system. All systems, locks, or other security devices should be examined periodically to ensure their proper operation.

The Examination Team should contact the Project or Regional Office and obtain information on the communication system, downstream warning system, auxiliary power sources, remote operating systems, emergency access routes, and contact personnel.

CHAPTER VI

ONSITE EXAMINATIONS

A. GENERAL COMMENTS

The onsite examination of a dam and its appurtenances is an essential part of the safety evaluation of the structure. Regional settings and materials characteristics influence the behavioral responses of dams, appurtenant structures, and their foundations, which have a direct relationship to the safe operation of the structures. The participants on onsite examinations should be able to identify potential hazards from conditions that have occurred progressively over a number of years and which local operators may not have recognized or that previous examinations did not detect. The onsite examination and evaluation must be guided and determined by continual awareness, recognition, and understanding of the primary causes of dam failures. The detection of changes, of indications of impending changes, and of developing structural and hydraulic weaknesses are fundamental objectives of the dam safety evaluations. The participants should also determine if the features are being operated as they were designed.

The intermediate onsite examination, which will often be conducted by a single Dam Safety Inspector, is identical in scope to the Examination Team examination described in this chapter. A Team, usually consisting of three members, will perform the formal examination. Therefore, the use of the word Team as used in this chapter can mean one or more persons.

Preexamination arrangements, scheduling, and coordination are necessary for an efficient and safe conduct of the examination and include the following:

- Advance operational scheduling
  - Outlet and spillway release changes
  - Power and safety clearances
- Dewatering
  - Basins, conduits, plunge pools
  - Galleries and chambers
- Erection of temporary facilities for personnel access and safety

- Special transport facilities
    - To the site
    - At the site
    - Visual examination by aerial flight
- Participant coordination
    - Local district operators and engineers
    - Regional operators
    - Non-Bureau participants
- Special arrangements for underwater examination teams

B. EXAMINATION ARRANGEMENTS

6–1. **Lodging and Transportation.**–One of the Team members should make all necessary arrangements for lodging and transportation as soon as an examination schedule is established. Lodging should be close to the damsite. Usually a member of the Project Office will make the lodging reservations upon request.

Team members are responsible for arranging their ground and air transportation between Denver and the site. The Project Office, in most cases, will provide the necessary ground transportation. If they are unable to supply the transportation, reservations should be made through a car rental agency. A Travel Authorization must be approved (or approval assured) prior to incurring any expenses.

6–2. **Equipment.**–The Team members should determine the equipment required for the examination and make arrangements to have it available for the examination. The equipment shall include:

(a) *Reference Materials.*–The Data Book should be reviewed before the Team conducts an onsite examination. A copy of the previous SEED Report, including convenient-sized drawings of specific features to be examined, and past Examination Reports should be kept available for ready reference during the examination.

(b) *Checklist.*–Ideally, a checklist should be developed for each dam or major structure to be examined. When new features are added or modifications are made to the existing structure, changes to the checklist should be made to keep it up to date. Each member of the Examination Team should review and revise as required the standard checklist for the specifics to be examined in their discipline during the onsite examination. The checklist should be a short outline of information and special instructions for conducting the examination. A special list of items requiring specific answers should be included with the main checklist. It is often helpful to include blank sheets with the checklist for additional notes and possible identification of photographs. Keep in mind that a checklist should be used as a guide and should not limit the examination. The checklists, upon completion of the Examination Report, should become a permanent part of the Data Book. Sample checklists can be found in appendix C for concrete and embankment dams.

(c) *Photography.*–At least one member of the Team (preferably more) should carry a camera. Telephoto and wide-angle lenses are very useful. A good quality flash attachment is also required. Color slides are preferred to color prints because of their versatility. The photographer should keep in mind that film is relatively inexpensive, so he should take photographs liberally. The amount of film required will depend on the complexity of the project to be examined. To get pictures of high quality, it is essential that the photographer be thoroughly familiar with the operation of the camera to be used.

The photographer should try to take photographs of a given subject in the same orientation as presented in past reports to facilitate a comparison of structural conditions in relation to time.

(d) *Examination Aids.*–A small steel pocket tape measure is very helpful. A good pair of 8- to 10-power field glasses improves the ability to observe inaccessible areas such as the abutments and faces of concrete dams and landslide areas. Other useful items which should be considered are: a checklist and/or a small notebook, pocket tape recorder, flashlight, thermometer, hand level, geologist's pick, Abney level, Brunton compass, and a probe.

Each Team member should have available a hardhat, approved safety boots, and safety glasses prior to making the onsite examination. The Project representative may be able to supply, upon request, such items as hip boots, rain coats, ropes, and major lighting equipment, if needed. The supplying of such items should be coordinated with a Project representative prior to the onsite examination.

6–3. Examination Scheduling.–The examination should be scheduled at a time when the water users will be the least inconvenienced, during a time of year when most features are visible, and when most of the equipment can be exercised during the examination. Desirable reservoir stages at the time of examination are (1) near maximum, (2) near normal, and (3) near minimum.

A responsible field representative familiar with the dam should be contacted. In most cases, the person would be a member of the Project Office. The field representative will be requested to supply information on the status of the dam and appurtenant features concerning the reservoir stage and releases for both the present and projected to the time of the examination. The Team should establish, as soon as possible, the facilities and equipment that should be operated during the visit, and to what extent. The proposed operations should be discussed with the field representative, who should determine if any of the operations require special authorization and so inform the Team. If desired, the Team should then request special authorization through the Assistant Commissioner–Engineering and Research. The field representative should arrange to have a responsible operator available during the examination. When the requested operation of equipment, such as gates or valves, cannot be accomplished during an examination, the Team should request that they be informed in advance of the date when the equipment could be operated. At that time, the Team should decide whether a Team representative should be present for the operation or if a written report of the operation would be satisfactory.

The Team should determine whether the stilling basins should be examined by dewatering or by using a diving team or whether the latest Examination Report is adequate. Examination of spillway and freeflow outlet works tunnels and conduits could require the use of a boat or ladder for access. The field representative should provide the necessary equipment for dewatering and access.

The Team should establish the length of time required for the examination. The complexity of the structures combined with reports of past examinations and discussions with the field representative should be used as a guide. There are occasions when it would be beneficial for the Team to fly over the site or examine the reservoir margins by boat. Sufficient time should be allotted to permit a thorough, unrushed examination of the facilities with ample time to revisit the site to check overlooked items and/or meet with Project personnel to discuss the findings of the examination.

C. FEATURES TO BE EXAMINED

This section discusses the structures, features, events, and evidence to be examined. Appendix B systematically tabulates them.

6–4. Dam and Auxiliary Dikes.–All recorded or observed events, incidents, or changes relating to the dam and appurtenances should be examined for their characteristics, locations, and recency. Many of the problems are generic or of a universal nature regardless of structure type or foundation class.

(a) ***Embankment (Earth and Rockfill) Dams.***–The external surfaces of an embankment dam can often provide clues to the behavior of the interior of the structure. For this reason, a thorough examination of all exposed surfaces of the dam should be made. If possible, field examinations should be performed when the reservoir is full and the embankment is subject to its maximum loadings.

The embankment should be carefully examined for any evidence of displacement, cracks, sinkholes, springs, wet spots, surface erosion, animal burrows, vegetation, etc. Any of these conditions, if not corrected, can ultimately lead to failure of the embankment.

Surface displacement on an embankment can often be detected by visual examination. Sighting along the alinement of embankment roads, parapet walls, utility lines, guardrails, longitudinal conduits, or other lineaments parallel or concentric to the embankment can reveal evidence of surface displacement. The crest should be examined for depressions which could decrease the freeboard. The upstream and downstream slopes and areas downstream of the embankment should be examined for any sign of bulging or other variance from smooth, uniform face planes. Any suspected movements identified by these methods should be verified by survey measurements.

Cracks on the surface of an embankment can be indicative of many potentially unsafe conditions. Surface cracks are often caused by dessication and shrinkage of materials near the surface of the embankment; however, the depth and orientation of the cracks should be determined to better understand their cause. Openings or escarpments on the embankment crest or slopes can identify slides and a close examination of these areas should be made to outline the location and extent of the slide mass. Surface cracks near the embankment-abutment contacts can be an indication of settlement of the embankment, and if severe enough, a path for leakage can develop along the contact. Therefore, these locations must be thoroughly examined. Cracks can also indicate differential settlement between embankment zones.

The downstream face and toe of the dam and areas downstream of the embankment should be examined for wet spots, boils, depressions, sinkholes, or springs which may indicate excessive seepage through the dam. Other indicators of seepage are soft spots, evaporites, abnormal growths of vegetation, and in colder climates, ice accumulation on areas where rapid snowmelt occurs. Seepage water should be examined for any suspended solids and, if solutioning is suspected, samples of the seepage and reservoir water should be collected for chemical analyses. Seepage water should be tested for taste and temperature to help identify its source. If saturated areas are located, they should be studied to determine if the wet spot(s) are a result of surface moisture, embankment seepage, or other sources. Wet areas, springs, and boils should be accurately located and mapped for comparison with future examinations. Seepage should be measured and monitored on a periodic basis to ensure that an adverse trend does not develop which could lead to an unsafe condition.

Drainage systems should be examined for chemical deposits, bacterial growth, deterioration, corrosion, or other obstructions which can plug the drains.

In addition to verifying anticipated embankment and foundation performance, instrumentation can also warn of developing unsafe conditions and should be examined for proper performance. Instrumentation most commonly installed in Bureau embankment dams consists of surface settlement and horizontal movement measurement points, internal horizontal and vertical movement installations, inclinometers, piezometers, and seepage measurement devices. Surface measurement points and internal movement installations should be examined for possible damage caused by vandalism, machinery activity, erosion, or frost heave. The security and the structural components of the piezometer terminal well, piping, and gages should be examined to ensure that the system is maintained in a manner such that dependable and continued readings can be obtained. Damage resulting from vandalism or machinery activity, improper backfilling, or lack of protective caps and enclosures can affect the performance of standpipe-type piezometers. Pipes or weirs used to measure seepage should be examined for obstructions, corrosion, deterioration, and erosion. In addition to noting deficiencies in existing instrumentation, areas where instrumentation is needed should be identified.

In addition to examining the embankment at high reservoir stages, the upstream face of the embankment and the reservoir area should be examined during periods of low reservoir stage when conditions permit. All upstream surfaces of the embankment should be examined for evidence of slides, sinkholes, or deterioration of slope protection. If storage levels do not permit examination, underwater examinations may be necessary. If a serious condition exists, the reservoir may require evacuation to facilitate examination of the upstream areas.

All surfaces of the embankment should be examined for signs of excessive erosion. Causes of the erosion such as inadequate slope protection, excessive rainfall, concentrated surface runoff, or the presence of highly erodible silts or dispersive clays should be identified. The area adjacent to all structures located within the embankment should be examined for erosion that could result in piping through the embankment.

Surfaces of the embankment, especially on smaller embankment dams, should be examined for animal burrows and vegetation. Any vegetation which has extensive root systems or prevents a clear view of the embankment or abutment areas should be removed. As previously mentioned, new vegetation and types of vegetation requiring large amounts of moisture should be suspect, as they may indicate wet spots on the embankment. A color difference noted within an area of the same type of vegetation is a good indication of wet spots on the embankment. Infrared photography can detect wet spots on an embankment.

(b) *Concrete Dams.*–Concrete dams encompass a variety of structures which include gravity, slab and buttress, multiple arch, and single arch dams. Regardless of the type of dam, all are subject to the same basic considerations with respect to safety.

The dam should be checked for indications of excessive stress and strain as well as signs of instability. Most dams have survey points and/or plumblines for regularly scheduled measurements of movement within the dam, the results of which can be plotted to determine the behavioral trend. There are obvious indications of movement which can be noted during an examination. A gravity dam can usually be checked by sighting along the parapets or handrails from one abutment to the other. Each contraction joint should be examined for evidence of differential movement between adjacent blocks. The joints should be examined for evidence of excessive expansion or contraction. The foundation contacts should be examined for any evidence of interaction with the foundation.

The concrete surfaces should be examined for leaching and deterioration caused by weather, unusual or extreme stress, alkali or other chemical reaction, erosion, cavitation, temperature differential, vandalism, etc. The concrete should be examined for indications of growth (swelling usually is caused by alkali reaction) such as pattern cracking, cracking at embedded metalwork, and differential movement.

All cracks and spalls on the dam faces and in the galleries should be examined. Gallery cracks should be examined to see if they coincide with face cracks. Cracks and spalls noted during past examinations should be evaluated for any change of condition. New cracks and spalls should be noted and examined to determine the type, such as tension or crushing, and the reasons for their existence. Photographic documentation of a crack or spall condition aids in evaluating the changes from one examination to the next.

Seepage should be examined to determine possible sources such as poor bond on lift lines, waterstop failure, structural cracks, etc. The quantity of seepage should be compared with previously observed seepage to determine if there has been any significant change in the flow for similar reservoir elevations. This may require reviewing the reservoir elevation versus seepage plots.

Drain and weep holes should be checked to determine if they are open and functioning as designed. Drains in the foundation and the dam should be examined to determine if there have been significant changes in their performance. Many times nonfunctioning drains are evident from visual examination, but most of the time the only indication of a developing problem is a change of flow rate.

6–5. **Abutments and Foundation.**–Critical areas of the abutments and foundations are usually covered and not available for direct examination. For this reason, considerable reliance must be placed on the review of records and documents during preparation for the onsite examination.

The original characteristics of the foundation and abutment materials as well as any changes that might have been revealed during construction and operation should be evaluated during the review of the instrumentation, ground water, and seepage data prior to the onsite examination. This review should identify general conditions and specific areas or features to be examined.

Examination of upstream portions of the abutments and foundation is normally not possible because of reservoir storage. Therefore, physical examination is typically limited to the downstream abutments, groins, and toe of the dam. Grouting and drainage tunnels, especially at concrete dams, may also be available for examination. Portions of the foundation areas of appurtenant structures may be exposed for examination. Weathering characteristics of typical foundation and abutment materials may be determined from exposures in nearby road cuts or other excavations. The effects of foundation material saturation are sometimes visible in exposures in the zone of reservoir fluctuation.

Reaction of structures often reflects foundation changes. Depressions or sags in the crest or slopes of an embankment dam might reflect embankment or foundation consolidation, solutioning, or piping.

Offsets in joints in concrete dams may reflect foundation changes or deficiencies. Appurtenant structures which have settled or are out of plumb indicate excessive foundation yielding or compression.

Indications of harmful seepage may be quite obvious or very subtle. Changes in measured flow from monitored drains, whether increases or decreases, are immediately suspect. Other indications of changes might be increased frequency of sump pump operation and the development of new or lush vegetation. Plots of water levels in observation wells and piezometers should be carefully checked and compared with reservoir stage and local precipitation.

It is often essential that seepage be controlled by effective filters. The presence of suspended particles in seepage water is evidence that piping is taking place and is cause for immediate concern. Failure to control piping can rapidly lead to failure.

When the possibility of solutioning exists, samples of reservoir water and seepage water should be collected for water quality analyses if such data are not already available. Such analyses can identify the soluble material. If the rate of seepage can be determined, the rate of solutioning can be estimated.

Examination of landslides in the vicinity of the dam and in the reservoir is discussed in section 6–7.

6–6. **Reservoir.**–The reservoir basin, although usually not directly affecting the stability of the dam, should be examined for features which may compromise the safe operation of the dam and reservoir.

The region around the reservoir should be examined for indications of problems which might affect the safety of the dam or reservoir. Landforms and regional geologic structures should be assessed. Areas of mineral, coal, gas, oil, and ground-water extractions should be examined. The region should be checked for subsidence indications such as sinkholes, trenches, and settlement of highways and structures. The reaction of other structures on the same formation may provide information on the possible behavior of the dam and appurtenances.

Whenever an examination is made, the elevation of the reservoir should be recorded. Any recent noteworthy high or low stages and any encroachment on the flood pool should be recorded.

If conditions permit, the reservoir basin should be examined during low reservoir stages. If this is not possible, then underwater examinations may be required of selected or suspicious locations.

The reservoir basin surfaces should be examined for depressions, sinkholes, or erosion of natural surfaces or reservoir linings. The reservoir basin should also be examined for excessive siltation which can adversely affect the loading of the dam or obstruct the inlet channels to the spillway or outlet works.

6–7. **Landslides**.–Landslides, as used here, include all forms of mass movement that can affect the dam, appurtenances, reservoir, or access routes. They include active, inactive, and potential slide areas which can range from minor slope raveling to large volume movements.

Team members should be knowledgeable about landslide causes, mechanisms, characteristics, symptoms, and treatment. Slide areas can often be identified and possibly delineated by numerous signs of distress or movement. These include escarpments, tilted trees, areas of dead or dying vegetation, tension cracks, hillside distortions, misalinement of linear features, encroachment of shoreline vegetation into the reservoir and springs. Documentation of existing conditions utilizing photographs is strongly suggested. If warranted, a slope stability survey and monumentation may be required.

Bureau dams and reservoirs usually have been investigated for existing and potential landslides and the results are included in the Landslide Register. The Register, therefore, provides excellent information for this part of the evaluation. However, the Register may not include information on all, especially recent slides. The Register might not identify potential slides due to onsite changes such as recreational developments. Team members should review all geologic reports and drawings, any available aerial photographs, and construction and operation histories. As part of their examination, the Team should include information and recommendations for updating the Landslide Register.

(a) *Reservoir Slides*.–Landslides entering a reservoir on occasion cause a surface wave capable of overtopping the dam, damaging appurtenances, or causing excessive erosion at critical points along the reservoir rim. Landslide characteristics of interest include size; orientation relative to reservoir configuration; distance from the dam, appurtenances, dikes, or critical rim sections; speed of failure; type of material; and failure mechanism.

Causes or triggering mechanisms could include earthquakes, reservoir drawdown, unusually high reservoir stages, undercutting by wave action, or saturation from excessive precipitation. Development around the reservoir can result in changes to the natural equilibrium by alteration of slopes, changes in the drainage pattern, and changes in ground-water table. Developments might include access roads, grading for recreational facilities, timber cutting, waste piles, leach fields, and drainage facilities.

The time available during a typical safety of dams examination is insufficient for an in-depth examination of each existing or potential reservoir slide area. Therefore, a review is necessary to determine the areas that should be examined. The identification of suspicious conditions should prompt a Team recommendation for an in-depth study to be performed.

(b) *Landslides in Vicinity of Dam and Access Roads.*–Excavations for the dam, appurtenances, and access roads disturb the natural slopes and drainage established throughout geologic time and in almost all cases result in a less stable condition. The presence of a reservoir invariably changes the ground-water regimen which, in turn, affects slope stability. While operating personnel are normally more familiar with conditions in the vicinity of the dam along commonly used access roads, personnel unfamiliar with the area can easily miss or not comprehend a symptom of slope instability which has been slow to develop. Team members should question the operations staff about any known slides in the area. Minor slope raveling can plug a drainage ditch leading to ponding of runoff and eventual saturation of slopes. Improperly maintained rockbolts and wire mesh can work loose, resulting in slope failures. Maintenance may tend to be neglected or deferred as a cost saving measure, often resulting in incipient landslides.

The effects of extreme precipitation on potential and existing slide areas along access routes should be evaluated. Similar evaluations should be made of slopes along intake channels and the tailwater channels to determine if the flow capacity characteristics of the spillway and outlet works are adversely affected. Slopes above access and control structures, whose failure could prevent access to or operation of the facility, should be examined.

6–8. Appurtenant Structures.–All appurtenant structures affecting the safe operation of the dam should be examined. The structures include the spillway, outlet works, power outlets, and canal outlets. Each of the structures may be composed of any or all of the following items:

(a) *Inlet and Outlet Channels.*–Practically every hydraulic structure is served by inlet and outlet channels composed of cut or fill slopes of soil or rock. A few spillways and "fuse plugs" have been constructed in soil or rock cuts or fills. Most soil or rock-lined spillways have a concrete or solid rock control section to reduce the seepage or erosion potential. Outlet works inlet channels are usually submerged and may require special underwater investigation.

The channels should have stable slopes and be free of sloughs, slides, and debris. The channels and slopes should be free of all forms of vegetative growth which will obstruct flows. The channels should be examined for evidence of sinkholes, boils, or piping. The channels should provide satisfactory clearance around intake and terminal structures so that the structures can operate hydraulically as designed. The channels should be examined for evidence of destructive eddy currents. The exit channels should be checked for excessive degradation which might adversely affect the hydraulic characteristics of the terminal structure.

The approach channel, especially for the spillway, should have some type of safety boom made of logs or floats to keep people and floating debris away from the intake structure. The safety boom should be properly anchored and show very little evidence of water logging of the floats or wear on the cable or chains and fasteners, and should have adequate slack for proper operation during high and low reservoir stages. These features should be observed for serviceability and the accumulation of any drift or debris.

(b) *Concrete Structures.*–The concrete portions of spillways, outlet works, and power outlets all serve similar basic hydraulic and structural functions; the examination techniques and objectives are therefore similar. The structures should be free of all unauthorized installations such as flashboards which reduce the discharge capacity through the structures. The concrete surfaces should be examined for deterioration caused by weathering, unusual or extreme stresses, alkali or other chemical reaction, erosion, cavitation, vandalism, etc. The structures (especially tower structures such as spillway drop intakes, outlet works intake, and cut-and-cover access shafts) should be examined for evidence of differential settlement. The alinement of channel wall structures should be examined, remembering that a cantilevered wall will deflect into the channel more than an adjacent wall panel which has the added support of counterforts or some other type of stiffener. The surfaces of wall and floor panels adjacent to and downstream from transverse contraction joints should be flush with or just slightly away from the flow line of the surface of the upstream panel, to prevent possible destruction of the downstream panel during high-velocity flows. All contraction joints should be free of vegetation. Aeration slots should be free of silt and debris. Tunnels and conduits should be examined for stress cracks, bulges, shifts of alinement, and excessive leakage. All passages, water and air, should be free of obstructions. Areas susceptible to collecting debris should be noted.

All fill adjacent to the structure should be examined for subsidence or an increase of depth caused by soil movement. The contacts between the fill and the structure should be examined for evidence of piping. All cut or fill slopes adjacent to the structure should be examined for unstable conditions.

The bridges and hoist decks, along with their supporting members, should be examined for condition and proper function. All guides for trashracks, gates, or other mechanical features should be in good condition. All drains should be open and show evidence of proper functioning. Drainage and seepage should be directed away from all metalwork such as electric conduits, pipes, and fixtures. Stilling basin drain air vents should be examined to determine if the screens are in place and the vents are open. The stain outlines, on the walls of the structures for various discharges, should be studied for an indication of flow characteristics through the structure. Channel protection adjacent to the energy dissipation structure should be examined to determine if it is performing as designed. Special attention should be given to the possibility that the material may wash either out of the channel or back into the structure during operation.

(c) *Mechanical Equipment.*—Mechanical and associated electrical equipment should be operated through the full operating range under actual operating conditions to determine that the equipment performs satisfactorily. The equipment should be checked for proper lubrication and smooth operation without binding, 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 accessible parts of the equipment should be examined for damaged, deteriorated, corroded, cavitated, loose, worn, or broken parts.

Wire ropes should be examined for proper lubrication. Deformed, broken, or rusted wires and ropes should be noted. Wire rope or chain connections at gates should be examined for worn or broken parts. Rubber or neoprene gate seals should be examined for deterioration, cracking, wear, and leakage. Hydraulic hoists and controls should be checked for oil leaks. Hoist piston and indicator stems should be examined for contamination and for rough areas that could damage packings. Gate stems and couplings should be examined for corrosion, broken or worn parts, and condition of the protective coating. Fluidways, leaves, metal seats, and seals of gates and valves should be examined for damage due to cavitation, wear, misalinement, corrosion, and leakage. Sump pumps should be examined and operated to verify reliability and satisfactory performance. Air vents for gates and valves should be checked to confirm that they are open and protected.

Operating instructions should be posted near associated equipment and checked for clarity. Each operating device should be permanently and clearly marked for easy identification. All equipment controls should be checked for proper security to ensure that unauthorized persons cannot operate or tamper with the equipment.

The reservoir level equipment should be checked for proper operation. Ice prevention systems should be operated to verify that all nozzles are functioning. Mechanical and associated electrical equipment should be examined for adequacy of ice and weather protection and for damage resulting from inadequate protection. Ventilating and heating systems should be operated and checked for adequate capacity to control damp environments for mechanical and electrical equipment. 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 determine if they are available and in good condition. The availability of equipment for moving, lifting, and placing of stoplogs, bulkheads, and trashracks should also be verified.

During or after the onsite examination, discussions should be held with the operator or dam tender to determine if there are any unusual operating conditions or problems with the equipment. The discussions and operation of equipment should be used to verify that the operator understands and is qualified to operate the equipment. Maintenance and exercising practices should also be discussed to determine that they are adequate and in accordance with the DOC and SOP.

The accessibility of controls for operation of critical gates during an emergency and under adverse weather conditions should be discussed. The possible need for remote controls should be considered. If conditions do not permit examination of an outlet or operation of gates or valves, an examination should be scheduled for a later date with Project and, if possible, ACER representatives present. If ACER personnel cannot be present, a report documenting the operating details should be submitted by the examining party to the ACER.

(d) *Auxiliary Power.*–An adequate auxiliary power supply should be provided for emergency operation of gates and other necessary equipment during periods when the normal source of power is not available. The auxiliary power supply should have sufficient capacity to operate at the maximum intended load as described in the DOC and SOP. The fuel supply should be sufficient to operate the auxiliary power unit for the maximum anticipated outage of the normal power supply.

During an examination, the auxiliary power supply should be used to operate gates and other equipment to determine if the system is operational and adequate. Fire protection, proper venting of exhaust gases, and protection against vandalism should be examined. Operating instructions, clearly describing the procedures required to manually place the auxiliary power supply in operation, should be posted. Automatic systems should be checked for proper operation. These systems do not normally require operating instructions. All switches and valves should be described in the instructions and clearly identified. The frequency of exercise, maintenance procedures, and operational problems should be discussed with the operator.

(e) *Access Roads.*–The safe operation of a dam depends on adequate and safe means of access. Usually the only access to a dam is by road. The road should be of all-weather construction suitable for the passage of automobiles and any required equipment for servicing the dam during any weather conditions. Surfacing material should be adequate to support anticipated loads. All cut and fill slopes, uphill and downhill from the road, should be stable under all conditions. The road surface and bridge decks should be located above the projected high-water line of any adjacent streams.

If the access road is not capable of satisfactory service during an emergency, alternate means of access should be readily obtainable, such as helicopter or jeep trails.

D. ONSITE EXAMINATION NOTES

Each member of the Examination Team should carry a checklist or a small notebook during the examination. The checklist should be categorized by structure notes and separated into individual items examined such as floors, walls, riprap, vegetation, etc. Notes should include (1) operational status of the reservoir at the time of the examination; (2) a list of the members of the examining party; and (3) special notes on the DOC, SOP, underwater examinations, landslide potential, instrumentation, communications, auxiliary power, access roads, and safety features. Sample checklists can be found in appendix C.

E. ONSITE DISCUSSIONS

6–9. Discussions With Operating Personnel.–Members of the Examination Team should discuss the operation of each appurtenant feature of the dam with the dam tender or operator. The discussion may indicate if the features are operating as designed. The discussion will also serve to pinpoint problems which might require further investigations.

6–10. Discussions With Non-Bureau Participants.–Members of the Examination Team should discuss freely with other Federal, State, and local officials all aspects of the examination. The discussions should include proposed examination procedures, items requiring attention, and specific items or conditions observed which are of special interest to non-Bureau participants.

F. ONSITE EXAMINATION

Depending on site location, size, age, and condition, each dam will be assigned a schedule for the intermediate examination. The intermediate examinations will usually be conducted by a Dam Safety Inspector, or a technical specialist from the Division of Dam Safety; however, on occasions, additional personnel may be required. Examinations will also determine the progress made in resolution of recommendations resulting from the previous SEED examinations and on changes in previously reported conditions or on new conditions at the damsite. The findings of the Dam Safety Inspector will be reported in an Examination Report to be completed and delivered to the Chief, Inspections Branch within 30 calendar days following completion of the onsite examination. Every 6 years a multidisciplined Team will be assembled to accomplish a formal safety examination of the dam.

G. EXAMINATION REPORT

An Examination Report shall be written upon completion of the onsite examination and the format is described in chapter VII.

CHAPTER VII

EXAMINATION REPORT

A. GENERAL

An Examination Report will be prepared following each onsite examination. The purpose of this Report is to provide the ACER (Assistant Commissioner–Engineering and Research) and others with documentation of the activities, findings, conclusions, and recommendations resulting from a dam safety examination. The Report is to concentrate on the Dam Safety Inspector or Examination Team's findings that have existing or potential dam safety significance. While brevity is intended, the scope of the Report's discussions of findings must provide sufficient information to ensure complete coverage of all pertinent features affecting the safety of the dam to fully support the conclusions and recommendations of the Report, and to answer specific questions that may arise from the recommendations. The Examination Report should be objective, straightforward, and comprehensive. The condition of the dam should be stated in a manner which gives credibility to the examination. The Examination Report is to be completed and delivered to the Chief, Inspections Branch within 30 calendar days following completion of the onsite examination.

B. REPORT CONTENTS

The Report will discuss briefly both the data reviewed and the operational status on the days of the onsite examination. In addition to the operational status on the days of the onsite examination, the date and elevation of the historical maximum reservoir level and the historical maximum spillway discharges should be provided. For comparison, the design maximum surcharge elevation and the design maximum spillway discharge should be listed as well as other historical operational events that are important to the dam's performance and evaluation for safety. Elements of structural safety of a dam discussed in appendixes A and B should be discussed in the Examination Report. The examination findings will be discussed by subject area to support conclusions and recommendations.

The Inspections Branch provides copies of a suggested format to be followed when a Dam Safety Inspector or Examination Team is preparing an Examination Report. While each Report must be tailored to the dam examined and the site conditions to be reported, a suggested format does produce some uniformity in presentation of information collected. A copy of the currently suggested Examination Report format, or a copy of a recently prepared Examination Report can be obtained from the Division of Dam Safety.

The terms satisfactory, fair, poor, and unsatisfactory are used in a general sense throughout the Examination Report describing the structural or the operational condition of the equipment; but, when they appear capitalized in the SEED Report they denote the overall classification of the dam as follows:

- SATISFACTORY

  No existing or potential dam safety deficiencies are recognized. Safe performance is expected under all anticipated loading conditions, including such events as the MCE (maximum credible earthquake) and the PMF (probable maximum flood).

- FAIR

  No existing dam safety deficiencies are recognized for normal loading conditions. Infrequent hydrologic and/or seismic events would probably result in a dam safety deficiency.

- CONDITIONALLY POOR

  A potential dam safety deficiency is recognized for unusual loading conditions which may realistically occur during the expected life of the structure. CONDITIONALLY 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.

- POOR

  A potential dam safety deficiency is clearly recognized for normal loading conditions. Immediate actions to resolve the deficiency are recommended; reservoir restrictions may be necessary until problem resolution.

- UNSATISFACTORY

  A dam safety deficiency exists for normal conditions. Immediate remedial action is required for problem resolution.

Photographs, particularly of irregularities, should be taken during the onsite examination, referenced in the text, and included as an appendix to the Report. General drawings, which show location, plans and sections of dam, spillway, and outlet works should be included as an appendix to the Report.

C. CONCLUSIONS AND RECOMMENDATIONS

The culmination of the Examination Team's Report is the conclusions and recommendations. Conclusions and recommendations must be supported from the findings within the Report. Each conclusion should be identified separately in sequence. Each recommendation must result from a conclusion. Recommendations should be written concisely and identify, to the extent of knowledge available to the Examination Team, the specific actions to be taken. The first word in the recommendation should be an action word (e.g., "Prepare" or "Perform"). The recommendations should address all identified structural safety concerns of the Team. Each recommendation will be identified with a two-number and one-letter code (e.g., 80-SOD-A). The numbers shall identify the calendar year of the examination. The letters will be assigned consecutively beginning with A.

D. SELECTED ITEMS TO BE CONSIDERED FOR INCLUSION IN THE EXAMINATION REPORT

When the Examination Team determines that the data necessary to complete their evaluation are unavailable, inadequate, or incomplete, every effort should be made to obtain the missing data before making a final evaluation. However, when missing information or data cannot be found in the records, the necessary data should be identified in the Report and a recommendation made to obtain it through additional investigation and/or testing.

An appraisal as to the adequacy of the IDF (inflow design flood) will usually occur in advance of assembling the Examination Team. An up-to-date IDF must be considered in the flood routing studies to be evaluated. If the IDF is not current, the Team should recommend that the hydrologic data be brought up to date and new flood routing studies be made.

Each geologic review should be considered unique because conditions, defects, and the inherent characteristics of the dam are dissimilar at each site. Two basic questions on geologic adequacy need to be answered. Were any geologic conditions different than anticipated? If so, why? The "why" will most likely involve one or more of the following reasons: (1) inadequate foundation preparation, (2) inadequate exploration, and/or (3) unexpected conditions. The need for new geological data is most often based on judgment. Recommendations to elicit new geologic data should identify the specific question of geologic adequacy to be answered.

Preliminary seismic site evaluations have been prepared for selected dams located in seismically active regions. Dams which have not been analyzed using modern design earthquakes should be examined for the need of such studies. The USGS (U.S. Geological Survey) "Open File Report 76-416" by Algermissen and Perkins [15] provides one data source for use in site seismicity studies. Detailed geologic maps, both USGS and State, and historic event records are additional sources on more precise regional basis. Based on data available, the reviewer must evaluate the potential seismic risk and recommend whether a preliminary or more elaborate seismic site evaluation should be given a high priority.

Review of past design analyses and procedures should include a comparison with present state-of-the-art methods. The review needs to evaluate the design and construction adequacy of the dam, spillway, outlet works, and other appurtenances required for safe performance. The analyses to be evaluated include those for structural stability (static and dynamic, internal and external), seepage and drainage control, freeboard, hydraulic performance, and equipment operation during both normal and emergency operations. If any analysis is considered outmoded or inaccurate, studies using the updated analytical methods should be recommended. An example of an analysis which has developed rapidly in recent years is the dynamic stress analysis for concrete and embankment (earth and rockfill) dams. Previously performed analysis generally include seismic loads by applying an estimated base acceleration. Most recent analysis are using MCE, design accelerogram, and response spectrum. As new analyses are completed, the structural integrity of the dam can be more fully assessed. Conclusions should be provided on (1) the design comparison of the original dam and appurtenances with present state-of-the-art design practices; (2) irregularities, inadequate structural response or less than present state-of-the-art practices discovered during the review of construction, and operations history; and (3) observations of potential distress in structures during the onsite examination.

Instrumentation is used to monitor the behavior of a dam and its foundation. When instrumentation data are available, the results of the past performance should be assessed. If instrumentation is lacking, the need for instrumentation to monitor specific aspects of dam behavior during the operational cycles should be recommended. When no instrumentation data or plots are available, an evaluation of the past behavior of the dam can only be determined by the onsite examination which is, at best, a surface observation. Conclusions should be presented on instrumentation, and recommendations made on specific items of structural performance that need to be instrumented.

E. REPORT EXCLUSIONS

The Examination Report is not intended to be a complete documentation on the dam evaluated. Background information, in addition to that required to support the dam safety concerns of the Examination Team, should not be included within the Report.

The review of record data by the Examination Team will include recent RO&M (Review of Operation and Maintenance) items in the conclusions or recommendations of the Examination Report. Occasionally, there are items related to maintenance or preventive maintenance which are being neglected and, if continued to be neglected, may significantly affect the safety of the dam. A conclusion stating the importance of items of this nature should be in the Examination Report when the maintenance item has the potential to rapidly develop into a significant threat to the safety of the dam. Also, a recommendation for ACER monitoring of the problem resolution may be appropriate. If an item of such concern is not currently included in the RO&M recommendation schedule, a description of the item should be prepared and included with the list of O&M observations from the Examination Team. The Examination Team's list of O&M observations should not duplicate any outstanding RO&M recommendations. The Team's listing of O&M observations will be transmitted to the Division of Water and Land Technical Services for evaluation of their possible inclusion in the RO&M program, when RO&M personnel do not participate in the onsite examination.

F. SIGNATURES

The Examination Team Members should sign the Examination Report. When Team Members are consultants who have signed their individually prepared report and the Examination Report only excerpts information from their report prepared to fulfill contractual obligation they need not sign the Examination Report. Their participation as a member of the Examination Team should be identified in the Examination Report.

G. DISTRIBUTION

After a review by the Chief, Inspections Branch the Examination Report will be distributed as follows:

Copies to	Number of copies
SEED Program Manager, D-3320	2
Dam Safety Support Branch, D-3390	1
Examination Team Leader, D-3310	1
Data Book, D-3310	1

H. REPORTS PREPARED FOR DAM SAFETY EXAMINATIONS CONDUCTED FOR OTHER AGENCIES

When dams are examined and evaluated by the Bureau for other agencies, the same general SEED Examination Team procedures for onsite examination and reporting will be followed. The significant differences are that the agency responsible for the dam will provide available design, construction, and operating data to the Bureau for preparation of the Data Book and for evaluation in advance of the onsite examination; and the agency is responsible for initiating all activities required to follow up the Team's recommendations and the analysis in the SEED Report. When specifically requested, the Bureau may agree to provide further engineering studies or advisory services beyond that covered in the SEED Report.

The requested number of copies of the SEED Reports will be transmitted to the agency office that requested and paid for the examination with a letter indicating the Bureau's completed work and continuing responsibility, if any. One copy will be forwarded to the Commissioner, Attn D-200; another copy will be delivered to the

Dam Safety Coordinator of the agency that requested the examination.

CHAPTER VIII

TECHNICAL ANALYSIS

8–1. **General.**–The engineering and geologic safety of dams issues identified from the onsite examinations as well as from other sources are entered into a computerized SOD (Safety of Dams) Register and prioritized as to their level of seriousness. In this way, all dams are prioritized with respect to the significant issues and studies can then be scheduled according to the critical nature of the identified issues. The SOD issues are then analyzed by technical specialists (engineers, geologists, or hydrologists) to form an Analysis Report and combined with the Examination Report, Instrumentation Report, and a Management Summary form a SEED (Safety Evaluation of Existing Dams) Report for the dam. The SEED Report gives an overall classification of the level of integrity for the dam as SATISFACTORY, FAIR, CONDITIONALLY POOR, POOR, OR UNSATISFACTORY. (Definitions for these classifications are given in chapter VII, section B.)

8–2. **Technical Analyses.**–The type of recommendations analyzed encompass a wide range of issues that can normally be expected to apply to storage dams and typically include consequences of failure, hydrology/hydraulics, geology, earthquake engineering, geotechnical issues, and structural issues. The analyses are conducted in two phases. Phase I is a technical assessment using available data and conservative assumptions to determine if the identified potential problem is a SOD deficiency. If the results of this phase are inconclusive, then a Phase II study is scheduled. Phase II is a more in-depth study and may include field investigations and laboratory tests to establish design parameters. The scope of Phase I analyses within each major area is generally as follows: A thorough review of the existing Data Book, Examination Report, Operation and Maintenance Records, the Technical Record of Design and Construction, as well as any new or additional information available, is undertaken by an engineer or geologist in each discipline to gain background knowledge about an individual dam. After this background information is reviewed, the technical analyses are initiated on the recommendations and problems stated in the Examination Report. During both phases of the analysis process, the potential problems of seepage, stability, and seismicity often require a multidisciplinary approach and may require an onsite examination by selected or multidiscipline engineers or geologists. With the completion of the Phase I analyses, the technical assessment can conclude that:

- No further action is required because the threat to safety of the dam is low or negligible.
- Immediate hazard-mitigating action is necessary because a threat to the safety of the dam is determined to exist.
- Additional field or analytical (Phase II) studies are required to assess the issues.

These studies could involve surface and subsurface exploration which may require drilling, sampling, laboratory testing, instrumentation installation, or other types of field investigations necessary to provide new data for Phase II analysis.

8–3. **Consequences of Failure.**–If the results of the engineering and geologic analyses indicate a potential safety of dams problem exists, available flood maps prepared by the regions or other sources will be examined to determine the consequences of failure. If no such maps exist, additional studies are performed to determine the consequences of a failure. This study is undertaken to determine the urgency of any future studies and is based on downstream flood routing using the following criteria:

- USGS 7-1/2-minute quadrangle maps, if available.

- $Q_B = 75\ D^{1.85}$ (for earth dams)

  Where Q_B is the peak flow through the breach in cubic feet per second due to failure by overtopping. (Q_B may be modified up or down depending on reservoir size, valley characteristics or other pertinent factors considered by the analyst.) D is the hydraulic depth in feet (vertical distance from the downstream toe to the reservoir water surface level at the time of the breach). This version of the equation was first used in Bureau of Reclamation inundation mapping guidelines, dated June 1980. It represents the discharge from a dam breach during the simultaneous occurrence of a PMF (probable maximum flood), and is based on an envelope curve covering the available historical data from measured and estimated dam failure discharges.

- The least distance limit of reconnaissance-level mapping for purposes of these analyses is defined by one of the following criteria:

  (a) A major watercourse or reservoir exists of sufficient capacity to safely dispose of potential floodwaters.

  (b) A major tributary is capable of supplying floods of peak discharge equivalent to 50 percent of the Q_B from dam break.

Based on the flood maps and criteria given in section 8–3, hazards associated with these inundation levels can be estimated.

- If a town, village, or population center is obviously affected this fact is stated and the recommendation made that the dam be evaluated for modification. The discussion should identify and evaluate, in general terms, the alternatives that are likely available to contain the decision-level flood.

- If the flood plain maps show the inundated area to be sparsely populated throughout their limit, a field trip is often conducted to verify the extent of hazards. The existence of limited hazards may result in a recommendation that a probability-based decision analysis be made in the evaluation of the dam for modifications.

8–4. Hydrologic/Hydraulic Evaluation.–The purpose of the evaluation is to provide:

- Flood routings to determine the possibility of overtopping the existing structure by a recently approved IDF (inflow design flood) or PMF inflow hydrograph.

- A reconnaissance-level assessment of downstream hazards that may be inundated should the existing dam fail.

- A review of conditions in the upstream basin, particularly for use changes such as new urban developments or storage dams.

- A definition of future analysis that is required.

The hydrologic/hydraulic evaluation will typically include the following:

- The PMF hydrograph will be routed through the reservoir using conservative routing assumptions.

  (a) If overtopping occurs, the peak discharge, depth, and duration (assuming no dam failure) will be determined.

  (b) If overtopping does not occur, the amount of freeboard, peak spillway discharge, and duration above maximum design discharge or similar information will be determined.

- If routing the PMF threatens the safety of the dam, return period flood hydrographs (i.e., 1,000 year, 500 year, 100 year) will be routed through the dam. In the absence of the frequency data, floods equal to various percentages of the peak and volume of the PMF will be routed through the dam and the impact on the dam and downstream channel determined. As required, other floods will be routed to determine the magnitude of flood at which overtopping of the dam occurs.

Items accomplished by other programs or reserved for more detailed Phase II analyses include:

(a) Preparation of a detailed inundation map and flood profile for any modified conditions.

(b) Inclusion of existing and proposed land use patterns on inundation maps.

(c) Assignment of costs associated with any degree of flooding.

(d) Flood frequency calculations.

(e) Inundation maps for other frequency floods.

(f) Preparation of project design or structural modification alternatives.

8-5. Geologic Evaluation.–The primary areas of geologic concern are the reservoir rim, abutment stability, seepage, and landslide hazards. Geologic analysis must often locate or establish knowledge on detail rock structure, seismicity and seismic-related effects, and geophysical properties of embankments and foundations. The analysis will consist of a review of geophysical data, instrumentation, records, and reports of past seepage, ground-water movements, study of the material's properties and structures, and remote sensing interpretations of aerial photography.

The analysis to develop seismicity at a site will require a review of the records and reports dealing with seismicity and remote sensing interpretation. Two general approaches may be utilized both dependent upon whether the damsite is east or west of the eastern boundary of the Rocky Mountains. Within and west of the Rocky Mountains, a deterministic approach is generally possible but probabilistic methods may be employed alone or together with deterministic methods. A deterministic approach utilizes fault characteristics and seismicity combined with epicentral distances to determine potential earthquake loading. East of the Rocky Mountains Seismotectonic Province, a probabilistic approach is more feasible and utilizes recurrence based on historical seismicity to determine potential earthquake loading. Foundation materials subject to liquefaction, the potential for fault offsets in the dam foundation and abutments, and mass reservoir foundation movements are further considerations in any assessment of performance at a damsite during an earthquake.

The geologic contribution frequently includes an interpretive discussion on the review of geologic records, reports, and geologic mapping to provide information regarding rock structure, such as bedding, joints, faults, or foliation. In addition, results of new remote sensing studies are provided as inclusions in the geologic analyses.

For recommended Phase II analyses, geologists need intimate involvement in the definition of field investigative programs to collect additional data or samples.

8–6. Earthquake Stability.–In areas of low and infrequent seismic loading (i.e., most of Uniform Building Code [16] Seismic Zones 2, 1, and 0), the initial analyses are often conducted using simplifications and conservatively selected seismic shortcuts data and assumed properties. If this conservative analysis shows the dam to be safe, no further work will be required. In areas of more severe and/or frequent seismic loading (i.e., Uniform Building Code Seismic Zones 4 and 3, and in other zones where appropriate), and in the case where an initial simple analysis does not demonstrate the dam to be safe, more sophisticated analyses are required.

(a) *Dynamic Stability (Deformation) Analyses.*–Generally, analyses incorporating the time dependence of the ground acceleration and the dynamic response will be conducted (i.e., more sophisticated than pseudostatic).

(1) Embankment Dams–The initial step will be a simplified SEED analysis utilizing the NRC (Nuclear Regulatory Commission) response spectrum. Local site effects are not considered in the determination of the spectral amplitudes. Results to be obtained include:

- The permanent displacements along assumed failure surfaces extending through the top one-fourth, the top one-half, and the full height of the embankment resulting from the critical MCE's (maximum credible earthquakes) and/or approximate probabilistic earthquakes.

- The epicentral distances of magnitude M = 6-1/2, 7-1/2, and 8-1/4 events which would cause a 3-foot permanent deformation along a failure surface extending through a critical section of the embankment.

More sophisticated Phase II analyses would then be conducted as needed.

The more sophisticated analyses are usually staged (i.e., be progressively more exact) until either the dam is demonstrated safe or determined to be unsafe which is usually more difficult.

(2) Concrete Gravity Dams–The initial step will be a simplified response spectrum analysis utilizing the NRC response spectrum. Local site effects are not considered in the determination of the spectral amplitudes. Results to be obtained include:

- Peak stresses in critical elements, factors of safety for overturning and sliding, or analysis by energy methods if the factor of safety is below 1.0 resulting from the critical MCE's and approximate probabilistic earthquakes.

- The epicentral distances of magnitude M = 6-1/2, 7-1/2, and 8-1/4 events which cause critical elements to become overstressed, or yield factors of safety of 1.0 for overturning and sliding.

(3) Arch and Other Concrete Dams–The initial step will be a simplified response spectrum analysis. Details of the analyses vary from case to case. Results to be obtained include, as applicable, the ones listed for concrete dams above.

(4) Appurtenant Structures–The level of analysis varies from a simple qualitative assessment to more detailed response spectrum analyses depending on the importance of the appurtenance to the overall safety of the dam.

(b) *Liquefaction Analyses.*–Liquefaction analyses will be conducted for all foundations and embankments where an initial assessment indicates the presence of potentially liquefiable materials. The initial analyses would be by simplified methods. Further, Phase II analyses would be performed to the extent required.

(c) *Fault Offsets Through the Dam and/or Abutments.*–The effects of fault offsets would be assessed on a case-by-case basis.

(d) *Seiche.*–The effects of seiche arising from ground accelerations (i.e., not faulting or landsliding) in the reservoir considering oscillations perpendicular to and parallel to the dam would be investigated. If the earthquakes under consideration have significant energy content at these periods, then a simplified modal superposition analysis will be conducted and the resultant wave amplitudes estimated. Further Phase II analyses would be accomplished as needed including the effects of overtopping of the dam.

(e) *Landslides and Fault Displacement Waves.*–The effects of landslide and fault offset generated waves in the reservoir are assessed on a case-by-case basis.

(f) *Geophysics.*–The geophysical programs have two major facets in the SEED program. One facet is to locate anomalies along an earth dam or foundation. If such anomalies exist, the usual procedure is to recommend further exploration, such as drilling, to define materials properties. The other facet includes the use of shear wave velocities derived from seismic surveys to be used for seismic stability analyses.

The various geophysical techniques and how their implications are used for SEED investigations follow:

(1) Seismic Refraction and Reflection–This method measures layered compressional and ground roll velocities. If there are any changes in a dam's earth materials, then a velocity anomaly will be generated. The ground roll velocities approximate shear wave velocities and may be used as a parameter in determining the dynamic response of an earth dam when shear wave velocities are not available.

(2) Seismic Shear Wave Velocity Investigations–Shear waves are measured by downhole, crosshole, and uphole methods using a standard refraction seismograph as the recorder. Shear wave velocities are used as one of the key parameters in the determination of the dynamic response of an earth dam.

(3) Radar Surveys–Radar surveys measure reflections from any interface which has a contrast in its complex dielectric

properties. Radar is used to locate voids in concrete, voids behind tunnel walls, and to evaluate soils at shallow depths.

(4) Resistivity Surveys–Resistivity surveys measure the electrical properties of soil and rock. Resistivity is primarily used to locate the phreatic surface through earth embankments.

8–7. Geotechnical Evaluation.–The performance of the structure under prior maximum loading condition often provides a partial basis for assessment. The quality of performance is judged on the structure's visual condition as described by inspecting engineers and the instrumentation records when available.

All available instrumentation data are reviewed during the evaluation. If no data or limited data are available, a determination is made as to whether additional instrumentation is required to assess a potential dam safety problem.

An assessment of the structural stability and seepage control integrity of the embankment and foundation under static loads is made for each dam. The extent of the assessment will vary in each case and depends on the following factors:

- Visual condition of the embankment and foundation
- Operation and performance record
- Structural and hydraulic height of the embankment
- Embankment zoning and exterior slope steepness
- Reservoir capacity, operational procedures, and evacuation capability
- Consequences of dam failure
- Hazard category
- Relevant engineering and geologic information available

The static stability of the embankment and foundation will be analyzed for settlement, displacement, and sloughing. Data such as geologic maps, drill logs, laboratory tests, phreatic surface, and construction methods will be used when available. Shear strength assumptions for analysis are based on material types, gradations, and compaction methods, and will usually assume that a long-term, consolidated, drained strength condition has been established. Phreatic surfaces are estimated utilizing piezometric data, when available, or are assumed, based on embankment zoning and slope configuration. Stability analyses will normally be performed for a steady-state seepage condition. Sudden drawdown analyses will be performed on a case-by-case basis as determined from factors such as whether the storage dam is "onstream" or "offstream," drawdown (reservoir evacuation) capability of outlet works, the drainage capability of the embankment zones, and if the reservoir has the potential of refilling suddenly from a flood before a drawdown slide could be repaired.

The seepage stability of the embankment and foundation is assessed. The analysis will focus on items such as increased seepage with time, the presence of sinkholes, cavities, or sandboils, and will utilize information records in the evaluation. Seepage analyses such as critical gradients, flow-net construction, and finite elements are performed, as required, and when sufficient data are available. The seepage control integrity of filters, drains, blankets, and transition zone materials is also analyzed.

Phase II analysis requirements will be identified when results of Phase I slope stability and seepage stability analyses indicate a low or marginal factor of safety. Additional investigations or studies may also be recommended when items such as increased seepage with time or the presence of sinkholes, cavities, or sandboils are identified. Phase II requirements may include field drilling, sampling, laboratory testing, installing and monitoring of instrumentation, and analyzing the results of these functions.

8–8. Miscellaneous Evaluations.–In addition, a wide variety of other issues may be identified at storage and diversion dams which do not fall into the above categories. These issues typically consist of the need to examine underwater features, install emergency power, test spillway gates, and other items. The level of analysis and urgency for accomplishment and/or resolution of these items must be identified on a case-by-case basis. Detailed guidance for this wide range of issues is beyond the scope of this manual, but engineers making their technical analysis need to be aware of when they exist.

CHAPTER IX

SEED REPORT

A. GENERAL

The Division of Dam Safety is responsible for preparing a SEED Report on each dam. The purpose of the Report is to present in a single document the information assembled from the review of pertinent documents, the onsite observations, the SEED recommendations, the analysis of the recommendations, and any future investigation and/or analysis which would aid in determining whether the dam and appurtenances were safe or needed a safety of dams modification. The Report will be reviewed and updated as required following each formal or intermediate safety evaluation.

The SEED Report will include a Management Summary, an Examination Report, an Analysis Report, and an Instrumentation Report.

Enclosures to a SEED Report include pertinent correspondence, analyses information, field and laboratory data obtained during SEED activities, and selected consultant reports.

B. DISTRIBUTION

The final SEED Report (6 copies) is transmitted to the Regional Director with information copies to the following:

Copies to	Number of copies
Commissioner, Attn: 200	1
Chief Engineer, D-200	1
Chief, Division of Dam and Waterway Design, D-210	1
Chief, Division of Electrical, Mechanical, and Plant Design, D-215	1
Chief, Concrete Dams Branch, D-220	1
Dam Safety Coordinator, D-220S	1
Chief, Embankment Dams Branch, D-230	1

Copies to	Number of copies
Chief, Division of Water and Land Technical Services, D-400	1
Chief, Division of Planning Technical Services, D-700	1
Chief, Library Branch, D-950	2
Chief, Division of Research and Laboratory Services, D-1500	1
Chief, Division of Geology, D-1600	1
Chief, Western Geology Branch (Dam Safety Coordinator), D-1610	1
or Chief, Central Geology Branch (Dam Safety Coordinator), D-1620	
Chief, Office of Technical Review and Management Services, D-3200	1
Chief, Inspections Branch, D-3310	2
SEED Program Manager, D-3320	1
Chief, Structural Behavior Branch, D-3350	2

A copy of just the transmittal memorandum is sent to Codes D-1630 and D-3390.

CHAPTER X

BIBLIOGRAPHY

A. GENERAL

The following references were selected to provide engineers and geologists with a general background on many of the factors affecting dam safety. It should be noted that the list is not meant to be complete. However, the references cited in these articles can serve as guides to other articles by which Team members can extend their knowledge of the causes and modes of dam failures, or articles which may directly relate to conditions existing at specific structures to be examined.

B. BIBLIOGRAPHY

10–1. Referenced in Text.–

[1] "Recommended Guidelines for Safety Inspection of Dams," Office of the Chief of Engineers, Department of the Army, Washington, D.C., May 1975.

[2] "National Program of Inspection of Dams," vols. 1-5, Office of the Chief of Engineers, Department of the Army, Washington, D.C., 1975.

[3] Report by General John W. Morris, Chief of Engineers, Department of the Army, to the January 31, 1978 Annual Meeting of USCOLD, Charleston, S.C.

[4] "Safety of Dams, A Review of the Program of the U.S. Bureau of Reclamation for the Safety of Existing Dams," National Research Council, Committee on the Safety of Dams, 1977.

[5] "Model Law for State Supervision of Safety of Dams and Reservoirs," USCOLD Committee on Model Legislation for Safety of Dams, New York, N.Y., 1970.

[6] "Risks to Third Parties from Large Dams Report," ICOLD Committee on Risks to Third Parties from Large Dams, Paris, France, 1976.

[7] "Lessons from Dam Incidents," ICOLD Committee on Failures and Accidents to Large Dams, Paris, France, 1974.

[8] "Lessons from Dam Incidents, USA," ASCE/USCOLD Joint Publication, ASCE, New York, N.Y., pp. 6-16; 29-89, 1975.

[9] "Inspection, Maintenance, and Rehabilitation of Old Dams," Selected papers from Engineering Foundation Conference Proceedings, September 23-28, 1973, ASCE, New York, N.Y., 1974.

- Summary of the Session on Federal Inspection Activities, pp. 67-75.
- Summary of States Experiences in Dam Safety Regulation, pp. 86-104.
- Summary of International Experiences, pp. 262-271.
- Summaries of Sessions on Hydrology and Spillways, pp. 273-281.
- Safety Appraisal of Old Dams: An Undated Perspective, pp. 405-417.
- Mechanical Equipment Problems on Old Dams, pp. 440-450.
- Underwater Inspection by Submarine, pp. 459-463.
- Summary of Workshop on Foundations, pp. 541-557.
- When is Foundation Seepage Unsafe?, pp. 570-583.
- Foundations of Existing Dams—Seepage Control, pp. 584-608.
- Stability of Old Dams as Related to Their Foundations, pp. 688-696.
- General Report on Seismic Hazards and Problems, pp. 745-767.
- Potentially Active Faults in Dam Foundations, pp. 768-770.
- Inspection, Maintenance, and Remedial Treatment; San Francisco Water Department, pp. 849-870.
- Resolutions, pp. 905-906.

[10] "Safety of Small Dams," Engineering Foundation Conference Proceedings, August 4-9, 1974, Henniker, N.H., ASCE, New York, N.Y., 1975.

[11] "Responsibility and Liability of Public and Private Interest on Dams," Engineering Foundation Conference Proceedings, September 28–October 3, 1975, ASCE, New York, N.Y., 1976.

[12] "Evaluation of Dam Safety," Engineering Foundation Conference Proceedings, November 28–December 3, 1976, Pacific Grove, Calif., ASCE, New York, N.Y., 1977.

[13] "Report on the Bureau of Reclamation's Dam Safety Review," (Lange Report), Bureau of Reclamation Review Team, Denver, Colo., August 1977.

[14] "Summary Report of the Organization Review Committee (ORC)," Bureau of Reclamation, Denver, Colo., September 1977.

[15] Algermissen, S. T. and D. M. Perkins, "A Probabilistic Estimate of Maximum Acceleration in Rock in the Contiguous United States," Open File Report 76-416, United States Geological Survey, 1976.

[16] *Uniform Building Code*, International Conference of Building Officials, 1982.

10–2. Not Referenced in Text.–

"Evaluation of Dam Safety," Selected papers from Engineering Foundation Conference Proceedings, ASCE, New York, N.Y., 1976.

- The Malpasset Dam, pp. 72-136.
- Dam Safety Program of EBMUD, pp. 179-194.
- Evaluation of Seepage Stability of Dams, pp. 195-218.
- Unit Curves for Judging Spillway Adequacy, pp. 219-239.
- Identifying Potential Stability Problems, pp. 245-268.
- Latent Stability Deficiencies, pp. 269-273.
- Evaluation Guidelines for Spillway Adequacy, pp. 395-414.
- Downstream Hydrograph from Dam Failure, pp. 437-462.

Sowers, George F., "The Use and Misuse of Earth Dams," ***Consulting Engineer***, vol. 17, No. 1, pp. 106-114, July 1961.

Starr, Chauncey, "Social Benefit Versus Technological Risk," *Science*, vol. 165, pp. 1232-38, September 19, 1969.

Wiggins, John H., Jr., "The Balanced Risk Concept: New Approach to Earthquake Building Codes," *Civil Engineering-ASCE*, vol. 42, No. 8, p. 55, August 1972.

Biswas, Asit K. and Samar Chaterjee, "Dam Disasters: An Assessment," *Engineering Journal* (Canada), vol. 54, No. 3, pp. 3-8, March 1971.

Chaterjee, Samar and Asit K. Biswas, "The Human Dimensions of Dam Safety," *Water Power*, part 1, vol. 23, No. 12, pp. 446-453, December 1971; part 2, vol. 24, No. 1, pp. 17-21, January 1972.

Taylor, Karl V., "Some Unusual Aspects of Dam Safety Studies in Western United States," 10th ICOLD, June 1970, Montreal, Question 38, Report 28, Transactions, vol. III, pp. 465-487, 1970.

Eberhardt, Andrew, "Judgment Factors in Inspection of Dams," *Water Power*, vol. 21, No. 11, pp. 431-435, November 1969.

Jansen, Robert B., Roy W. Carlson, and Edward L. Wilson, "Diagnosis and Treatment of Dams," 11th ICOLD, 1972, Madrid, Communication 14, Transactions, vol. IV, pp. 975-991, 1973.

Wilson, Stanley D., "Incompatibility of Materials and Effect on Dam Performance," *In* Recent Developments in the Design, Construction, and Performance of Embankment Dams Proceedings, University of California, Berkeley, June 16-20, 1975.

Johnson, Stanley J., "Comments on Lessons Learned Since 1968," *ibid.*

Deere, Don U. and Ralph B. Peck, "Problems of Dams Founded on Rock, Including Karstic Limestone, *ibid.*

"Review of Practices for Safety of Dams," U.S. Department of Agriculture, August 1977.

Shaw, Gaylord, "The Search for Dangerous Dams—A Program to Head Off Disaster," *Smithsonian*, vol. 9, No. 1, pp. 36-45, April 1978.

"Actions Needed to Increase the Safety of Dams Built by the Bureau of Reclamation and the Corps of Engineers," Report of the Comptroller General of the United States, June 3, 1977.

Coal Refuse Inspection Manual, U.S. Department of the Interior, Mining Enforcement and Safety Administration, April 1976.

"Improving Federal Dam Safety," Report of the Federal Coordinating Council for Science Engineering and Technology, November 15, 1977.

Bureau of Reclamation, *Dams and Public Safety*, Jansen, Robert B., Revised Reprint, 1983.

Bureau of Reclamation, *Training for Dam Operators—A Manual for Instructors*, September, 1981.

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

APPENDIX A

CONSIDERATIONS FOR MAKING SAFETY EVALUATIONS

CONTENTS

CONSIDERATIONS FOR MAKING SAFETY EVALUATIONS

1. GENERAL

Appendix A provides a comprehensive list of actions, studies, and reviews which must be considered in determining if a dam is safe. Some items will not be applicable to all dams nor are all items of equal significance. The plan, design, construction, and operation concepts are those commonly applied to Bureau facilities. Bureau terminology has been used.

2. GEOLOGY

(a) Review geologic mapping, plans, and cross sections showing all exploration features and summarizing drill logs and geologic interpretations, to include at least the dam, appurtenant structures, materials sources, and if available, the reservoir geology. Particular attention should be paid to geologic features which influence design considerations such as: shear zones; faults; open fractures; seams, joints, fissures, or caverns; landslides; variability of formations; compressible or liquefiable materials; weak bedding planes, etc.

(b) Review detailed exploration logs, including lithologic and physical condition of materials encountered, water test data, standard penetration or other resistance testing results, and frequency and types of samples obtained for laboratory testing.

(c) Review geophysical data.

(d) Review water level records of ground water in the vicinity before and after the reservoir was filled.

(e) Review petrographic or chemical studies of foundation materials and natural construction materials.

(f) Review geologic portions of all reports relevant to the site, from preliminary reconnaissance studies to final, as-built records.

(g) Review aerial photographs of site and reservoir.

(h) Review published or unpublished regional geologic studies that are relevant to the dam and reservoir setting.

(i) Examine the pertinent features of the areal geology at the dam and appurtenant sites, borrow and quarry sites, and, to the extent practicable, in the reservoir basin. Examine representative core recovered from site exploration, particularly from zones indicated on the logs as being badly broken, weathered, or highly pervious.

(j) On the basis of general geologic setting, is this an acceptable site for the type of dam selected? Are attitudes of bedding and joints particularly favorable or unfavorable to seepage, slope stability, foundation stability, acceptance of dam and reservoir loads and pressures, and sliding?

(k) Was the effect of raised ground-water levels on the stability of abutment and reservoir slopes considered?

(l) Was potential chemical activity—reactivity of aggregate, quality of surface and ground water, type cement, solutioning of gypsum—adequately evaluated?

(m) Was foundation susceptible to improvement by treatments such as pressure grouting, slurry grouting, blanket grouting, drainage, dental concrete, and deeper or more extensive excavation?

(n) Assess adequacy of overall exploration program.

(o) Did geologic information gathered during construction correlate with that originally available to designers? If there were any significant differences, was the actual treatment of the geologic conditions adequate to compensate for changed conditions? If anticipated quantities of borrow and other materials were not obtainable from primary sources, were the alternative sources sufficiently similar?

(p) Was adequate geologic information available?

(q) Identify all documents reviewed. List as references in the reports being prepared. (Very important.)

3. SEISMICITY

(a) Review seismic and tectonic history of region—published and unpublished literature.

(b) Review seismic history of site-published and unpublished literature, including NOAA records.

(c) Determine location and relative influence of active and potentially active faults which could affect the project site. For sites located in California, reference the Alquist-Priolo special studies zones and status of the "Active Fault Mapping and Evaluation Program."

(d) Consider all potential earthquake effects which could influence the project site such as:

- Surface rupture
- Ground tilting
- Elevation changes
- Shaking
- Landsliding
- Slumping
- Liquefaction
- Settlement
- Seiches

(e) Review design earthquake—location, magnitude, and recurrence interval.

(f) Review MCE (maximum credible earthquake) for design—location, magnitude, and recurrence interval.

(g) Were expected baserock motions for design earthquakes developed? What are they and how were they developed? Are design accelerograms available?

(h) Were pseudostatic "g" factor(s) recommended for design? How were they determined?

(i) Is there a potential for reservoir-induced seismicity?

(j) Review aerial photographs and space imagery of site and region.

(k) Was adequate information available to designers?

(l) Identify all documents reviewed. List as references in the reports. (Very important.)

4. HYDROLOGY AND SPILLWAY DESIGN FLOODS

(a) Review summary hydrologic data contained in project reports.

(b) Review design reports, operations and maintenance manuals, and contract plans and specifications regarding spillway and outlet facilities for familiarization with design.

(c) Review design flood criteria:

- Upstream reservoirs and diversions.
- Downstream risk evaluation.
- PMF (probable maximum flood) or return frequency flood adopted for design.

(d) Review design storm precipitation, duration, and runoff values:[2]

- Storm distribution with time.
- Assumed snowpack conditions.
- Assumed snowmelt rates.
- Watershed characteristics—Antecedent moisture, vegetation type, topography, land use, etc.

(e) Review flood routing studies:

- Reservoir area—capacity curve.
- Spillway rating curve (gated or uncontrolled).
- Flood routing analysis.
- Assumed reservoir water surface prior to design flood inflow.
- Maximum flood surcharge level.
- Residual freeboard between crest of dam and maximum flood surcharge level.

(f) Review flood control storage criteria:

- Seasonal storage requirements.
- Seasonal flood potentials.
- Potential operational conflicts.
- Normal outlet releases.

(g) If spillway is gated:

- Review seasonal gate operation procedures and schedules.
- Do the flood routing studies consider gate malfunctions and any redundant provisions for passing floods?

[2] The Hydrology Branch of the Division of Planning Technical Services evaluates the inflow design flood and furnishes their findings to the Division of Dam Safety in advance of the formal examination.

(h) Review downstream flood plain conditions:

- Limits of improved channel and/or flood levees.
- Areas of potential inundation for IDF (inflow design flood) discharges.
- Proximity of developed areas.
- Was a postulated failure study made and an inundation map prepared?

(i) In light of the present state-of-the-art and postconstruction hydrological records, has the spillway capacity been reevaluated?

(j) Identify all documents reviewed. List as references in report being prepared. (Very important.)

5. EMBANKMENT (EARTH AND ROCKFILL) DAMS

5.1 General

(a) Review plans and specifications, construction and as-built drawings, and design reports for general familiarization and understanding of intent.

(b) Review basic design including dam layout, cross sections and zoning, specified foundation treatment, and grouting. Note any unusual aspects or omissions.

(c) Review summarized exploration, geology, and seismicity data for dam and reservoir, and evaluate. Note potential adverse effects of known geologic features and aspects requiring more detailed review. Assess critical geologic features as related to dam safety. Evaluate general adequacy of exploratory programs. Evaluate potential for liquefaction of the foundation soils.

(d) Review laboratory test procedures and results.

(e) Review adopted foundation and embankment materials design properties and compare with exploration and field and laboratory test results for appropriateness. Evaluate compatibility of the dam and foundation.

(f) Review summarized stability analyses, including the loading and operational conditions analyzed. Note any apparent deficiencies and/or unusual appearing results. Were currently acceptable methods of analyses performed, such as the finite element method?

(g) Review as-built drawings and data including foundation configuration, grouting summaries, drainage provisions, construction changes, type and depth of cutoff, foundation discontinuities, special foundation treatment, etc., and assess their potential effects on performance.

(h) Review changed conditions claims, corrective action memorandums, and construction change orders. Assess for relationship to safety and performance of dam and appurtenances.

(i) Review construction photographs.

(j) Review summarized construction control test results. Compare these with the design-phase exploration and test results and with the design assumptions.

(k) Compare summarized materials and foundation properties determined during construction with general criteria used for design. Assess adequacy of criteria and specifications provisions from safety standpoint with regard to specific items such as seepage control, capacity, and clogging potential of foundation and interior drains, piping potential, etc.

(l) Evaluate design criteria and methods of analyses and their relationships to present state-of-the-art.

(m) Are there any activities in the region such as mining or oil or water extraction which could adversely affect the dam?

(n) Evaluate whether construction specifications, procedures, and materials are compatible with general design assumptions and known site conditions.

(o) Review instrumentation installations and assess adequacy of instrumentation for monitoring probable operational performance in general or for specifically identified behavioral patterns.

(p) Review instrumentation records and evaluate significance of results.

(q) Conduct detailed examination of site and environs. Note and record any unusual or suspect conditions such as springs and seeps, distressed areas, etc. Observe selected drill cores, if available.

(r) Evaluate possible effects of freezing and thawing on structural and functional aspects of dam environment.

(s) Assess implications of results of reviews with respect to possible catastrophic failure of the dam.

(t) Was adequate information available to designers? If not, what was lacking?

(u) Was design and construction in accord with the state-of-the-art at the time?

(v) How would design and construction compare with present state-of-the-art?

(w) Identify all documents reviewed. List as references in the report being prepared. (Very important.)

5.2 Materials Properties—Placement, Testing, and Control

(a) Classification, gradation, Atterberg limits.

(b) Proctor densities for fine-grained materials, relative density for coarse-grained materials. Optimum moisture.

(c) Freeze-thaw (riprap durability).

(d) Consolidation and settlement.

(e) Dispersive clay tests, solubility tests.

(f) Filter and drain materials, gradation, permeability, etc.

(g) Petrographic and minerological descriptions.

(h) Lift thickness, compactive effort, method of compaction.

(i) Number and distribution of control tests. Variation of density and moisture.

(j) Select material and placement methods at abutments and around structures.

(k) Variability of material in borrow areas.

(l) Relative settlement of adjacent zones.

(m) Dynamic and static strength properties (friction angle and cohesion).

5.3 Foundation

(a) Methods used in determining the strength and behavioral characteristics of the foundation mass.

(b) Extent of foundation investigation—area covered—number and type of exploratory holes.

(c) Summary of grouting—depth, take, pressures, additives, and mixes.

(d) Drain holes, seepage, and uplift control systems.

(e) Strike and dip of joint system.

(f) Specified foundation treatment.

(g) Size and location of seams and shears.

(h) Characteristics of any joint fillings.

(i) Soil density and potential for liquefaction.

5.4 Analytical Data

(a) Method of analysis—finite element, slip circle, wedge, etc. What materials, engineering properties (strength, etc.), were used? Were they valid?

(b) How was foundation deformation considered?

(c) What loading conditions were adopted?

(d) Results of analysis—stresses, strain, displacements, stability factors, foundation pressures.

(e) Was any analysis made of pore pressure distribution within the dam and foundation?

(f) Was analysis made of seepage distribution within the dam and foundation?

(g) Were the abutments analyzed?

(h) Compare computed and measured deformations in dam and foundation.

(i) Was uplift and fracturing caused by grouting considered and monitored?

6. CONCRETE DAMS

6.1 General

(a) Review plans and specifications, construction and as-built drawings, and design reports for general familiarization and understanding of intent.

(b) Review basic design including dam layout, cross sections, specified foundation treatment, and grouting. Note any unusual aspect or omissions.

(c) Review basic geologic features and aspects requiring more detailed review. Assess critical geologic and seismic features as related to dam safety. Evaluate general adequacy of exploratory programs including abutment integrity with respect to downstream rock wall failures.

(d) Review laboratory test procedures and results.

(e) Review adopted foundation and concrete materials design properties and compare with exploration and field and laboratory test results for appropriateness. Evaluate compatibility of the dam and foundation.

(f) Review summarized results of stress analyses or stability analyses, including loading and operational conditions analyzed. Note any apparent deficiencies and/or unusual appearing results.

(g) Review as-built drawings and data, including foundation configuration, foundation and joint grouting summaries, drainage provisions, construction changes, etc., and assess their potential effects on performance.

(h) Review changed conditions claims, corrective action memorandums, and construction change orders. Assess for relationship to safety and performance of dam and appurtenances.

(i) Review construction photographs.

(j) Review summarized construction control test results and record test results. Compare these with the design-phase exploration and test results and with the design assumptions.

(k) Compare summarized materials and foundation properties determined during construction with general criteria used for design. Assess adequacy of criteria from safety standpoint.

(l) Evaluate design criteria and methods of analyses and their relationship to present state-of-the-art.

(m) Are there any activities in the region such as mining or oil or water extraction which could adversely affect the dam?

(n) Evaluate whether construction specifications, procedures, and materials are compatible with general design assumptions and known site conditions.

(o) Review instrumentation installations in dam and foundation and assess adequacy of instrumentation for monitoring probable operational performance in general or for specifically identified behavioral patterns.

(p) Review instrumentation records and evaluate significance of results.

(q) Conduct detailed examination of site and environs. Note and record any unusual or suspect conditions such as springs and seeps, concrete cracking, distressed areas, etc. Observe selected drill cores, if available.

(r) Evaluate possible effects of freezing and thawing on structural and operational aspects of dam.

(s) Assess results of reviews and their relationship to possible catastrophic failure of the dam.

(t) Was adequate information available to designers? If not, what was lacking?

(u) Was design and construction in accord with the state-of-the-art at the time?

(v) How would design and construction compare with present state-of-the-art?

(w) Identify all documents reviewed. List as references in the report being prepared. (Very important.)

6.2 Material Properties—Placement, Testing, and Control

(a) Strength and durability of concrete employed—90-day strength, etc.; size of cylinders (design vs. construction values), coefficient of variation—high and low values—number of cylinders.

(b) Modulus of rupture and elasticity of concrete.

(c) Were any cores taken from dam and tested? How do the results compare with design criteria?

(d) Type of cement, cement factor, admixtures, and water-cement ratio. What tests were conducted on the cement used? Proportions of concrete mix? Was the creep property of concrete determined?

(e) Lift height and method of placement.

(f) Treatment of vertical or contraction joints and lift surfaces.

(g) Concrete placement and joint grouting schedule—as performed.

(h) Heat generation characteristics of the concrete mixes.

(i) Physical, chemical, and mineralogical characteristics and sources of aggregates used.

6.3 Foundation

(a) Methods used in determining the strength and behavioral characteristics of the rock mass.

(b) Extent of foundation investigation—area covered—number and type of exploratory holes—tunnels—geophysical methods.

(c) Summary of grouting—depth, take, pressures, additives, and mixes.

(d) Drain holes, seepage, and uplift control systems.

(e) Strike and dip of joint system.

(f) Specified foundation treatment.

(g) Size and location of seams and shears.

(h) Characteristics of any joint fillings.

6.4 Analytical Data

(a) Method of analysis—trial load—finite element—number of cantilevers—arches, etc.

(b) How was foundation deformation considered?

(c) How was the effect of vertical loading prior to grouting handled?

(d) What loading conditions were adopted?

(e) What temperature variation was assumed?

(f) When were construction joints grouted relative to construction sequence?

(g) How much cooling occurred prior to grouting?

(h) Results of analysis—stresses, thrust, movements, stability factors, shear-friction safety factors, foundation pressures.

(i) Was any analysis made of pressure distribution within the foundation?

(j) Abutments radial or nonradial?

(k) Shear keys in vertical or contraction joints?

(l) Was the effect of cracked sections included?

(m) Were the abutments analyzed?

(n) Impact forces of water in plunge pool (arch dams only).

(o) Compare computed and measured stresses and deformations in dam and foundation.

7. APPURTENANT STRUCTURES

7.1 General

(a) Review contract plans and specifications, construction and as-built drawings, and design reports for general familiarization and understanding of intent.

(b) Review basic design, including plans, sections, details, assumptions, and criteria. Note any unusual aspects and omissions.

(c) Review summarized exploration, geology, and seismicity data for site and reservoir, and evaluate. Note potential adverse effects of known geologic features and aspects requiring more detailed review. Assess critical geologic features in relation to performance aspects of appurtenances which may have a bearing on dam safety.

(d) Review laboratory and hydraulic model test procedures and results.

(e) Review adopted foundation, concrete and steel reinforcement design properties, and compare with exploration, field and laboratory test results, and generally accepted practice, for appropriateness. Evaluate compatibility of the structure with its foundation and environment.

(f) Review summarized results of stress and stability analyses, including loading and operational conditions analyzed. Note any apparent deficiencies and/or unusual appearing results.

(g) Review as-built drawings and data, including foundation configuration, grouting summaries, drainage provisions, construction changes, etc., and assess their potential effects on performance.

(h) Review changed conditions claims, corrective action memorandums, and construction change orders; and assess potential impact on performance.

(i) Review construction photographs.

(j) Review summarized construction control test results. Compare these results with design phase exploration and test results and with design assumptions.

(k) Compare summarized materials and foundation properties determined during construction with general criteria used for design. Assess adequacy of criteria from safety standpoint.

(l) Evaluate design criteria and methods of analyses and their relationships to present state-of-the-art.

(m) Are there any activities in the region such as mining or oil or water extraction which could affect the structures?

(o) Evaluate whether construction specifications, procedures, and materials are compatible with general design assumptions and known site conditions.

(p) Review instrumentation installation and assess adequacy of instrumentation for monitoring probable operational performance.

(q) Review instrumentation records and evaluate significance of results.

(r) Conduct detailed examination of structures. Note and record any unusual or suspect conditions such as springs and seeps, concrete cracking, distressed areas, etc. Observe selected drill cores, if available.

(s) Evaluate possible effects of freezing and thawing on structural and operational service of structures.

(t) Assess results of reviews and their relationship to possible catastrophic failure of the dam.

(u) Was adequate information available to designers? If not, what was lacking?

(v) Was design and construction in accord with the state-of-the-art at the time?

(w) How would design and construction compare with present state-of-the-art?

(x) Identify all documents reviewed. List as references in the report being prepared. (Very important.)

7.2 Spillway

(a) Hydraulic evaluations.—Evaluate spillway capability to pass all design floods without endangering the dam. If the spillway has control gates, evaluate redundant provisions for safely passing floods should the gates fail to fully operate for any reason. Review provisions (log booms, etc.) for keeping spillway entrance free of obstructions.

(b) Structural evaluations.—Review and evaluate the following relevant to the security of the dam:

(1) Geologic data regarding the spillway foundation and compatibility with structural design.

(2) Design criteria in comparison with generally accepted standards. The evaluation would include review of the various combinations of loading for which components of the spillway facility might be subjected, such as:

- Earth loads
- Hydrostatic loads
- Uplift forces
- Dynamic water forces
- Earthquake forces

(3) Design of seepage cutoffs and drainage provisions behind spillway walls and beneath floor slabs.

(4) Energy dissipation features.

7.3 Outlet Works Structures and Controls

Review and evaluate the following items relevant to the security of the dam:

(a) Design criteria with regard to hydraulic and structural requirements.

(b) Operational criteria including capability of outlets to reduce or completely withdraw reservoir storage in event of emergency.

(c) Geologic conditions and any potentially adverse effects on structural or operational requirements.

(d) Backup systems available in event of operational malfunctions.

(e) Energy dissipation features.

7.4 Material Properties for Spillways and Outlets—Placement, Testing, and Control

(a) Strength and durability of concrete employed—90-day strength, etc., size of cylinders (design vs. construction values), coefficient of variation—high and low values—number of cylinders.

(b) Modulus of rupture and elasticity of concrete.

(c) Type of cement, cement factor, admixtures, and water-cement ratio. What tests were conducted on cement? Proportions of the concrete mix?

(d) Methods of concrete placement.

(e) Treatment of construction and contraction joints.

(f) Physical, chemical, and mineralogical characteristics and sources of aggregates.

(g) Properties of steel reinforcement.

(h) Did the properties of the materials actually used conform with design assumptions?

7.5 Foundations of Spillways and Outlets

(a) Methods used in determining the strength and behavior characteristics of the supporting rock.

(b) Extent of foundation investigation—area covered—number and type of exploratory holes.

(c) Summary of grouting—depth, take, pressures, mixes, additives.

(d) Drain holes, seepage, and uplift control systems.

(e) Strike and dip of joint system.

(f) Specified foundation treatment.

(g) Size and location of seams and shears.

(h) Characteristics of any joint fillings.

7.6 Analytical Data for Spillways and Outlets

(a) Were methods of analysis adequate and appropriate?

(b) How were foundation characteristics handled?

(c) Were adopted loading conditions adequate and appropriate?

(d) Results of analyses—stresses, stability factors.

(e) Evaluate anticipated hydraulic performance of energy dissipation features, channel or conduit flow patterns, and scour resistance.

8. OPERATION AND MAINTENANCE

(a) If dam and reservoir have not yet been placed in initial or full service, review criteria for initial filling of the reservoir with regard to actual operating conditions. From the review of geology, design, and construction and instrumentation records, assess the effects of sudden reservoir loading and saturation on the dam and foundation.

(b) Review reservoir topography and geology and assess reservoir landslide potential.

(c) Review the DOC (Designers' Operating Criteria) and SOP's (Standing Operating Procedures) or similar documents for the project. Note particularly the operational capability of outlets to reduce reservoir storage in an emergency, the redundant systems available to operate gated spillways and outlet works during power and operational malfunctions, and the adequacy of emergency instructions to operating personnel. Identify project operation and maintenance factors relating to the safety of the dam. Are these factors adequately covered by the manufacturer?

(d) How often are operators at the dam? Are their authority and responsibility regarding dam safety clearly defined?

(e) What criteria have been established for routine safety examinations and dam surveillance? What reporting procedures accompany these examinations, and who is responsible that operational questions regarding dam safety receive prompt and adequate attention?

(f) Identify any operational aspects related to dam safety which require further clarification or development.

(g) Do any upstream or downstream projects adversely affect operation of the dam or reservoir with respect to dam safety?

(h) Identify all documents reviewed. List as references in the report being prepared. (Very important.)

APPENDIX B

STRUCTURES, FEATURES, EVENTS, AND EVIDENCE TO BE EXAMINED

CONTENTS

1. GENERAL

The performance of dams and appurtenant structures is controlled by (1) their designs, (2) the characteristics of their constituent materials, (3) the nature of their foundations, and (4) their regional settings.

The fundamental objective of dam safety examinations is the detection of any existing or developing structural or hydraulic weakness evident from the complex interrelationships of those "performance controllers." In searching for weaknesses, dam examiners must recognize and understand these interrelationships.

2. CHANGES IN THE CHARACTERISTICS OF MATERIALS

2.1 **General.**–Observe for defective, inferior, unsuited, or deteriorated materials. A variety of different materials makes up the different type of dams and appurtenances. The quality and durability of these "building blocks" must always be determined in every instance and the need for such critical examination and what to look for as listed in this section are not normally repeated in the sections on specific structures.

2.2 **Concrete.**–(1) Alkali-aggregate reaction, and pattern crazing and cracking, (2) leaching, (3) frost action, (4) abrasion, (5) spalling, (6) general deterioration, and (7) strength loss.

2.3 **Rock.**–(1) Disintegration, (2) softening, and (3) dissolution.

2.4 **Soils.**–(1) Degradation, (2) dissolution, (3) loss of plasticity, (4) strength loss, and (5) mineralogical change.

2.5 **Soil-Cement.**–(1) Loss of cementation, and (2) crumbling.

2.6 **Metals.**–(1) Electrolysis, (2) corrosion, (3) stress corrosion, (4) fatigue, (5) tearing and rupture, and (6) galling.

2.7 **Timber.**–(1) Rotting, (2) shrinkage, (3) combustion, and (4) attack by organisms.

2.8 **Lining Fabrics.**–(1) Punctures, (2) seam partings, (3) light deterioration, (4) disintegration of boundary seals, and (5) loss of plasticity and flexibility.

2.9 **Rubber.**–(1) Hardening, (2) loss of elasticity, (3) heat deterioration, and (4) chemical degradation.

2.10 **Joint Sealers.**–(1) Loss of plasticity, (2) shrinkage, and (3) melting.

3. GENERIC OCCURRENCES

3.1 **General.**–Observe generic occurrences for their characteristics, locations, and recency. These occurrences are of a universal nature regardless of structure type or foundation class. The details of what to look for in observing these generic occurrences, actual or evidential, are not repeated in the sections on specific structures.

3.2 **Seepage and Leakage.**–(1) Discharge-stage relationship, (2) increasing or decreasing, (3) turbidity and piping, (4) color, (5) dissolved solids, (6) location and pattern, (7) temperature, (8) taste, (9) evidence of pressure, (10) boils, and (11) recency and duration.

3.3 **Drainage.**–(1) Obstructions, (2) chemical precipitates and deposits, (3) unimpeded outfall, (4) sump pump facilities, and (5) bacterial growth.

3.4 **Cavitation.**–(1) Surface pitting, (2) sonic evidence, (3) implosions, and (4) vapor pockets.

3.5 **Ice Action.**–Evidence of ice forces decreasing stability of structures, lifting gate hoists, obstructing gate leaves, and operational and mechanical installations.

3.6 **Stress and Strain–Evidence and Clues.**–(1) In concrete–cracks, crushing, displacements, offsets, shears, and creep; (2) in steel–cracks, extensions, contractions, bending, and buckling; (3) in timber–crushing, buckling, bending, shears, extensions, and compressions; and (4) in rock and soils–cracks, displacements, settlement, consolidation, subsidence, compression, and zones of extension and compression.

3.7 **Stability–Evidence and Clues.**–(1) In concrete and steel structures–tilting, tipping, sliding, and overturning; (2) in embankment structures, cutslopes, natural slopes–bulging, sloughing, slumping, sliding, cracks, and escarpments; and (3) in rock cutslopes, foundation, and unlined tunnels–slumps, slides, rockfalls, bulges, and cracks.

4. OPERATION AND MAINTENANCE

4.1 **Service Reliability of Outlet, Spillway, Sump Pump Mechanical-Electrical Features.**–(1) Broken or disconnected lift chains and cables, (2) test operation including auxiliary power sources, (3) reliability and service connections of primary power sources, (4) verification of operators' understanding and ability to operate, (5) ease and assurance of access to control stations, and (6) functioning of lubrication systems.

4.2 **Gate Chambers, Galleries, Tunnels, and Conduits.**–Ventilation and heat control of damp, corrosive environment of mechanical-electrical equipment.

4.3 **Accessibility and Visibility.**–(1) Obscuring vegetal overgrowth; (2) galleries, access ladders, and lighting; (3) access roads and bridges; and (4) communication and remote-control lines, cables, and telemetering systems.

4.4 **Control of Vegetation and Burrowing Animals.**–(1) Harmful vegetation on embankments–oversize, dead root channels; (2) harmful vegetation in structural concrete joints; (3) obstructing vegetal growth in hydraulic flow channels; and (4) ground squirrels, muskrats, and beavers.

5. BEHAVIOR

5.1 **General.**–Every attempt should be made to anticipate and have engineer-observers present onsite at times of large spillway and outlet discharges. Resident operational personnel can often supply valuable information and may be the only available observers (during earthquakes, for example).

5.2 **Warning, Safety, and Performance Instrumentation.**–(1) Piezometers, flow recorders, accelerometers, seismoscopes, joint meters and gage points, strain meters, stress meters, inclinometers, direct and inverted plumblines, surface reference monuments, stage recorders, and extensiometers; (2) serviceability; (3) access to readout stations; (4) type and location suitable for condition being observed; (5) need for recalibration; (6) faulty readings, sources, and reasons; (7) alarm systems operable and at appropriate set points; (8) random check readings during examinations; and (9) question operators to determine their understanding of purpose and functioning of instruments.

5.3 **During and After Large Floods.**–(1) Driftmarked high water lines; (2) evidence of taxed spillway capacity; and (3) undesirable or dangerous spillway flow patterns directly observed or deduced from flow strains, erosion trails, swept vegetation, and deposition of solids.

5.4 **During and After Large Outlet Releases.**–Undesirable or dangerous spillway flow patterns, dynamic pressures, vibrations, and cavitation sonics.

5.5 After Earthquakes.–(1) Cracks, displacements, and offsets in structural features; (2) cracks, slumps, slides, displacements, escarpments, settlements in embankments, cutslopes, and fill slopes; (3) broken stalactites in galleries, tunnels, chambers, and outlet conduits; (4) toppled mechanical equipment; (5) sand boils; and (6) general procedures established following an earthquake.

6. CONCRETE DAMS

(Many of these observations are applicable also to reservoir impounding power intake structures, spillway control structures, and lock walls.)

6.1 **Stress and Strain—Evidence and Clues.**–(1) Cracks, crushing, displacements, offsets in concrete monoliths, buttresses, face slabs, arch barrels visible on exterior surfaces and in galleries, valve and operating chambers, and conduit interior surfaces; (2) typical stress and temperature crack patterns in buttresses, pilasters, diaphragms, and arch barrels; and (3) retention of design forces in posttensioned anchorages and tendons.

6.2 **Stability—Evidence and Clues.**–(1) Excessive or maldistributed uplift pressures revealed by piezometers, pressure spurts from foundation drain holes, construction joints, and cracks; (2) differential displacements of adjacent monoliths, buttresses, and supported arch barrels or face slabs; (3) disparities in regions near the interface between arches and thrust blocks; (4) movement along construction joints; and (5) uplift on horizontal surfaces revealed by seepage on downstream face and in galleries at construction lift elevations.

6.3 **Hillsides and River Channels Adjacent to the Abutments and River Section Foundation Along the Downstream Toe of the Dam.**–(1) Leakage, (2) seepage, (3) stability, and (4) boils.

6.4 **Special Attention to Stability and Seepage Control at Discontinuities and Junctures.**–(1) Embankment wraparound sections, (2) waterstops in monoliths and face slabs, and (3) reservoir impounding backfill at spillway control sections and retaining walls.

6.5 **Foundation.**–(1) Piping of weathering products from old solution channels and rock joint structure; (2) efficiency of foundation seepage control systems—drains, drainage holes, grout curtains, cutoffs, and drainage tunnels; (3) history of shear zones, faults, and cavernous openings; (4) zones of varying permeability; (5) orientation of stratification and bedding planes-effect on permeability, uplift, and foundation stability; (6) subsurface erosion and piping; and (7) thin weaker interbeds-effect on stability.

7. EMBANKMENT (EARTH AND ROCKFILL) DAMS

7.1 **Stress and Strain—Evidence and Clues.**–(1) Settlement; (2) consolidation; (3) subsidence; (4) compressibility; (5) cracks, displacements, offsets, and joint opening changes in concrete facings on rockfills; (6) loss of freeboard from settlement; (7) zones of extension and compression visible along dam crest or elsewhere; (8) crushing of rock points of contact; (9) differential settlement of embankment cross-sectional zones visible along dam crest, indicating stress transfer along region of zone interface (increases possibility of hydraulic fracturing); and (10) fractures in outlet conduits.

7.2 **Stability—Evidence and Clues.**–(1) Cracks, displacements, openings, offsets, sloughs, slides, bulges, and escarpments on embankment crest and slopes and on hillsides adjacent to abutments; (2) sags and misalinements in parapet walls, guardrails, longitudinal conduits, or other lineaments parallel to embankment axis; (3) irregularities in alinement and variances from smooth, uniform face planes; and (4) bulges in ground surfaces beyond toes of slopes.

7.3 **Inadequate Seepage Control—Evidence and Clues.**–(1) Wet spots; (2) new vegetal growth; (3) seepage and leakage; (4) boils; (5) saturation patterns on slopes, hillsides, and in streambed; (6) depressions and sinkholes; and (7) evidence of high escape gradients.

7.4 **Erosion Control.**–(1) Loss, displacement, and deterioration of upstream face riprap, underlayment, and downstream face slope protection; and (2) beaching.

7.5 **Foundation.**–(1) See 6.5 also, (2) consolidation, and (3) liquefaction potential.

7.6 **Other Endangerments.**–(1) Utility pressure conduits on, over, or through embankments; and (2) diversion ditches along abutment hillsides.

8. SPILLWAYS

8.1 Approach Channel.–(1) Obstructions; and (2) slides, slumps, and cracks in cutslopes.

8.2 Log Booms.–(1) Submergence, (2) uncleared accumulated drift, (3) parting, (4) loss of anchorage, and (5) inadequate slack for low reservoir stages.

8.3 Hydraulic Control Structure.–(1) Stability, (2) retention of capacity rating, (3) erosion at toe, (4) unauthorized installations on crest, raising storage level, and decreasing spilling capacity, (5) gate piers, (6) trash control systems, (7) nappe and crotch aeration, and (8) siphon prime settings.

8.4 Headwater Control (Gates, Flashboards, Fuse Plugs, and Fabric Dams).–(1) Unauthorized position, (2) wedging, (3) gate trunnion displacements, (4) loss of gate anchorage posttensioning, (5) undesirable eccentric loads from variable positions of adjacent gates, (6) gate-seal binding, (7) erosive seal leakage, (8) failure of lubrication system, and (9) availability of bulkhead facilities for unwatering, and of cranes and lifting beams.

8.5 Operating Deck and Hoists.–(1) Broken or disconnected lift chains and cables; (2) unprotected exposure of electrical-mechanical equipment to weather, sabotage, and vandalism; and (3) structural members and connections.

8.6 Shafts, Conduits, and Tunnels.–(1) Vulnerability to obstruction; (2) evidence of excessive external overloading–pressure jets, contorted cross sections, cracks, displacements, and circumferential joints; (3) serviceability of linings (concrete and steel), materials deterioration, cavitation, and erosion; (4) rockfalls; (5) severe leakage about tunnel plugs; and (6) support system for pressure conduits in walk-in tunnels.

8.7 Bridges.–(1) Possibility of collapse with consequent flow obstruction, and (2) serviceability for operational and emergency equipment transport.

8.8 Discharge Carrier (Open Channel or Conduit).–(1) Vulnerability to obstruction; (2) evidence of excessive external sidewall loading–large wall deflections, cracks, and differential deflections at vertical joints; (3) invert anchorage and foundation support–drummy soundings, buckled lining, and excessive uplift; (4) observation or evidence of dangerous hydraulic flow patterns–cross waves, inadequate freeboard, wall climb, unwetted surfaces, uneven distribution, ride up on horizontal curves, negative pressures at vertical curves, pressure flow, and deposition; (5) drain system serviceable; (6) air ingestion and expulsion; (7) tendency for jump formation in conduits; and (8) buckling and slipping of slope lining; and (9) erosion of unlined channels.

8.9 Terminal Structures.–(1) Inadequate dissipation of energy, (2) jump sweepout, (3) undercutting, (4) retrogressive erosion, (5) loss of foundation support for flip bucket substructure, (6) unsafe jet trajectory and impingement, and (7) erosive endangerment of adjacent dam or other critical structures.

8.10 Return Channels.–(1) Impaired outfall; (2) obstructions; (3) slides, slumps, and cracks in cutslopes; (4) erosion or deposition creating dangerous tailwater elevations or velocities; and (5) evidence of destructive eddy currents.

9. OUTLETS

9.1 General.–Many of the observations made of outlet components are similar in nature and purpose to those made for spillway components, stilling basins for example.

9.2 Approach Channels (May Seldom be Directly Visible and May Require Underwater Examination.–(1) Siltation, and (2) underwater slides and slumps.

9.3 Intake Structures (Including Appended, Inclined, and Free-Standing Towers, Both Wet and Dry.–(1) Lack of dead storage; (2) siltation; (3) potential for burial by slides and slumps; (4) damage or destruction of emergency and service bulkhead installation facilities; (5) availability of bulkhead, cranes, and lifting beams; and (6) serviceability of access bridges.

9.4 Trashracks and Raking Equipment.–(1) Clogging of bar spacing, (2) lodged debris on horizontal surfaces, and (3) collapse.

9.5 Gate Chambers, Gates, Valves, Hoists, Controls, Electrical Equipment, and Air Demand Ducts.–(1) Accessibility to control station under all conditions; (2) ventilation; (3) unauthorized gate or valve positons; (4) binding of gate seals; (5) seizing; (6) erosive seal leakage; (7) failure of lubrication system; (8) drainage and sump pump serviceability; and (9) vulnerability to flooding under reservoir pressure through conduits, bypasses, and gate bonnets surfacing in chamber.

9.6 Conduits and Tunnels.–(1) See 8.6 also, (2) seepage or leakage along external periphery of conduit, (3) extension strains in conduits extending through embankments, and (4) capacity and serviceability of air relief and vacuum valves on conduits.

9.7 Terminal Structures.–See 8.9.

9.8 Return Channels.–See 8.10.

10. ENVIRONS

10.1 Reservoir.–(1) Stage at time of examination; (2) indications of recent noteworthy stages; (3) depressions and sinkholes in exposed reservoir basin surfaces; (4) massive water displacing slide potentials–leaning trees, escarpments, and hillside distortions; (5) flood pool encroachments; and (6) siltation adversely affecting loading on dam, and forming approach channel and waterway obstructions.

10.2 Reservoir Linings–Compacted, PCC (Portland Cement Concrete) and AC (Asphaltic Concrete), Fabric.–(1)Depressions and sinkholes; (2) erosion; and (3) animal disruption.

10.3 Downstream Proximity.–(1) Tailwater stage at time of examination, (2) reservoir connected springs; (3) endangering seepage or leakage regardless of source; and (4) river obstructions creating unanticipated tailwater elevations or interference with outfall channel capacities of the spillway and outlets.

10.4 Watershed.–(1) Surface changes that might materially affect runoff characteristics.

10.5 Regional Vicinity.–(1) Subsidence indications–sinkholes, trenches, subsidence surveys, settlements of buildings, highways, and other structures in the region; (2) assessment of land forms and regional geologic structure; and (3) records of mineral, hydrocarbon, and ground-water extractions, locations, producing horizons, accumulated production, and current rate of production.

10.6 Downstream Flood Plain.–(1) Limits of natural, improved, or leveed channel; (2) areas of potential inundation–for spillway design flood and for hypothetical failure; (3) proximity of developed areas; and (4) habitation, population, communication, and transportation corridors.

APPENDIX C

SAMPLE ONSITE EXAMINATION CHECKLISTS

CONTENTS

The following general checklists are examples to be followed but should be altered to fit the characteristics of a specific dam or structure. A brief description including dimensions, where needed, should be provided opposite each feature (Intake bulkhead, Gate structure, etc.).

________________ **DAM**

________________ **PROJECT**

________________ **REGION**

Date of Examination	**Structure Completed**
________________	________________

Operational Status at Time of Examination

Reservoir Water Surface–Elevation __________feet

Reservoir Storage __________acre-feet

Top of Active Conservation–Elevation __________feet

Maximum Reservoir Water Surface–Elevation __________feet

Historical Maximum Reservoir Level __________feet

Releases:

Spillway __________ft^3/s

Outlet Works __________ft^3/s

Canal __________ft^3/s

Powerplant __________ft^3/s

Examination Participants

Name	Affiliation

CHECKLIST FOR DESIGNERS' OPERATING CRITERIA AND STANDING OPERATING PROCEDURES

	DOC	SOP
Issue and revision dates	______	______
Is copy at dam current?	______	______
Are instructions adequate?	______	______
Are instructions understood?	______	______
Any changes needed?	______	______

EMERGENCY PREPAREDNESS

COMMUNICATIONS

Type

Normal	______	______
Standby	______	______
Adequacy	______	______

OPERATING PROCEDURES

Adequacy	______	______
Capability of personnel	______	______

AUXILIARY POWER

Test during examination	______	______
Condition	______	______
Adequacy	______	______

REMOTE CONTROL

Test during examination	______	______
Condition	______	______
Adequacy	______	______

ACCESS ROADS

Adequacy under adverse conditions ______ ______

SAFETY FEATURES

General condition ______ ______
Restricted areas ______ ______

CHECKLIST FOR EXAMINATION OF AN EMBANKMENT DAM

DAM

UPSTREAM FACE

Slope protection ______________________
Erosion–beaching ______________________
Vegetative growth ______________________
Settlement ______________________
Debris ______________________
Burrows or burrowing animals ______________________
Unusual conditions ______________________

DOWNSTREAM FACE

Signs of movement ______________________
Seepage or wet areas ______________________
Vegetative growth ______________________
Channelization ______________________
Condition of slope protection ______________________
Burrows or burrowing animals ______________________
Unusual conditions ______________________

ABUTMENTS

Seepage ______________________
Cracks, joints, and bedding planes ______________________
Channelization ______________________
Slides ______________________
Vegetation ______________________
Signs of movement ______________________

CREST

Surface cracking ______________________
Durability ______________________
Settlement ______________________
Lateral movement (alinement) ______________________
Camber ______________________

DAM–Continued

SEEPAGE AND DRAINAGE SUMMATION

Location(s) ______
Estimated flow(s) ______
Color (staining) ______
Erosion of outfall ______
Toe drain and relief wells ______

MEASUREMENT

Method ______
Amount ______
Change in flow ______
Clearness of flow ______

Color ______
Fines ______
Condition of measurement devices ______
Records ______

OTHER

______ ______
______ ______

PERFORMANCE INSTRUMENTS

Piezometer well

Well ______
Frostfloor ______
Ventilation ______
Gages ______
Piping ______
Security ______

Surface settlement points ______
Crossarm devices (deviation, station, and offset) ______
Reservoir-level gage ______
Ice-prevention system ______
Other

______ ______
______ ______
______ ______
______ ______

SPILLWAY

APPROACH CHANNEL

Vegetation (trees, willows, etc.) ____________________
Debris ____________________
Slides above channel ____________________
Channel side slope stability ____________________
Log boom ____________________
Slope protection ____________________

CONTROL STRUCTURES (OBSERVED OPERATION)

Apron

- Surface condition ____________________
- General condition of concrete ____________________
- Movement ____________________
- Settlement ____________________
- Joints ____________________
- Cracks ____________________

Crest

- Surface condition ____________________
- General condition of concrete ____________________
- Cracks or areas of distress ____________________
- Signs of movement ____________________

Walls

- Surface condition ____________________
- General condition of concrete ____________________
- Movement (offsets) ____________________
- Cracks or areas of distress ____________________
- Settlement ____________________
- Joints ____________________
- Drains ____________________
- Backfill ____________________

- Condition ____________________
- Hoist equipment ____________________
- Control equipment ____________________

SPILLWAY–Continued

CONTROL STRUCTURES–Continued

Bridge

Condition of piers ______________________
Surface of roadway slab ______________________
Structural condition of slab
and beams ______________________
Bridge bearings ______________________
Overall condition ______________________

CHUTE

Debris ______________________
Walls

Surface condition ______________________
General condition of concrete ______________________
Movement (offsets) ______________________
Settlement ______________________
Joints ______________________
Cracks or areas of distress ______________________
Condition of backfill ______________________

Floor

Surface condition ______________________
General condition of concrete ______________________
Movement ______________________
Settlement ______________________
Joints ______________________
Drains ______________________
Cracks ______________________

Drainage gallery

General condition of concrete ______________________
Movements (misalinement of
gallery) ______________________
Cracks ______________________
Drains ______________________

Amount of flow ______________________
Location of seeping drains ______________________

SPILLWAY–Continued

CHUTE–Continued

- Ventilation ______________________
- Lighting ______________________

STILLING BASIN

Debris in basin ______________________
Walls

- Surface condition ______________________
- General condition of concrete ______________________
- Movement (offsets) ______________________
- Settlement ______________________
- Joints ______________________
- Cracks or areas of distress ______________________
- Condition of backfill ______________________

Floor (if visible)

- Surface condition ______________________
- Condition of concrete ______________________
- Cracks or areas of distress ______________________
- Movement ______________________
- Joints ______________________
- Erosion ______________________

OUTLET CHANNEL

Slope protection ______________________
Stability of side slopes ______________________
Vegetation or other obstructions ______________________

OTHER

______________________ ______________________
______________________ ______________________
______________________ ______________________
______________________ ______________________

OUTLET WORKS

INLET WORKS (if visible)

Trashracks __________
Trashrack concrete structure __________
Intake bulkhead

- General condition __________
- Protective coating __________
- Seals __________

Inlet and upstream tunnel __________
Gate structure

- General condition __________
- Leakage __________
- Metalwork (air vent, bonnet cover, gate stems, watertight access door)
  - General condition __________
  - Protective coating __________

EMERGENCY CONTROL FACILITY

Security

- **Gate**
  - **General condition** __________
  - **Protective coating** __________
  - **Cavitation** __________
  - **Leakage (closed)** __________
  - **Exercising frequency** __________
  - **Operation at time of examination** __________
- **Control system**
  - **Mechanical** __________
  - **Electrical** __________
  - **Adequacy** __________

OUTLET WORKS–Continued

EMERGENCY CONTROL FACILITY–Continued

Access

- Concrete ____________________
- Metalworks ____________________
- Ventilation ____________________
- Lighting ____________________
- Leakage ____________________

Gate shaft

- Concrete ____________________
- Leakage ____________________
- Metalwork (gate items, stem handling equipment)
  - General ____________________
  - Protective coatings ____________________
- Gate hoist shelter house
  - General condition ____________________
  - Reservoir-level gage ____________________

OUTLET CONDUIT

Metalwork

- General condition ____________________
- Protective coatings ____________________
- Cavitation ____________________

Concrete

- General condition ____________________
- Leakage ____________________
- Settlement ____________________

Ventilation ____________________

Lighting ____________________

OUTLET WORKS–Continued

SERVICE CONTROL FACILITY

Valve or gate house

General condition ____________
Security ____________
Gate(s)

General conditions ____________
Protective coatings ____________
Cavitation ____________
Leakage (closed) ____________
Exercising frequency ____________
Operation of gates at time of examination ____________

Valve(s)

General conditions ____________
Protective coatings ____________
Cavitation ____________
Leakage (closed) ____________
Creep ____________
Exercising frequency ____________
Operation of valves at time of examination ____________

Control system for gates and valves

Mechanical ____________
Electrical ____________
Operating instructions ____________

OTHER

____________ ____________
____________ ____________
____________ ____________
____________ ____________

OUTLET WORKS–Continued

STILLING BASIN

Debris in basin ____________
Walls

- Surface condition ____________
- Concrete ____________
- Joints ____________
- Cracks ____________
- Backfill ____________
- Movement ____________

Floor (if visible)

- Surface condition ____________
- Stainless steel liner ____________
- Concrete ____________
- Joints ____________
- Signs of deterioration ____________
- Cracks ____________
- Cavitation ____________
- Movement ____________

OUTLET CHANNEL

Vegetation ____________
Gravel bars, etc. ____________
Riprap ____________
Stability of side slopes ____________

OTHER

____________ ____________
____________ ____________
____________ ____________
____________ ____________

POWER FEATURES

(If related to safe operation or structural integrity of dam)

INTAKE STRUCTURE ____________________

TRASHRACK ____________________

BULKHEAD GATE ____________________

INTAKE GATES ____________________

INTAKE GATE HOIST ____________________

GANTRY CRANE ____________________

Mechanical ____________________
Electrical ____________________
Paint ____________________
Operating instructions ____________________
Operation during examination ____________________
Storage area ____________________

PENSTOCK

Powerplant structure

Ceilings ____________________
Deck ____________________
Walls ____________________
Substructure ____________________

TAILRACE

Draft tube closure structure ____________________
Draft tube bulkhead ____________________
Gantry crane ____________________

STANDBY POWER UNIT

Condition ____________________
Exercising frequency ____________________
Automatic features ____________________
Operation during examination ____________________

RESERVOIR

LOG BOOM ____________________

LANDSLIDES ____________________

(Individual designation, location for identification, and description) ____________________

OTHER

____________________ ____________________

____________________ ____________________

____________________ ____________________

____________________ ____________________

ACCESS ROAD

CONDITION OF PAVEMENT ____________________

DITCHES ____________________

BRIDGE ____________________

General condition ____________________

Vegetation at abutments and piers ____________________

Bridge supports

- Foundations ____________________
- Substructures–piers ____________________
- Bridge bearings ____________________
- Moving parts ____________________
- Accumulation of birds' nests, etc. ____________________
- Visual examination of scour protection ____________________
- Protective coatings ____________________

ACCESS ROAD–Continued

BRIDGE–Continued

Main supporting members

- Deteriorated and/or damaged members ______________
- Protective coatings ______________

Bridge deck

- General condition ______________
- Drainage ______________
- Expansion joints ______________
- Guardrails ______________
- Signing ______________
- Live load capacity ______________

LOSS POTENTIAL (DURING EMERGENCY)

______________ ______________
______________ ______________
______________ ______________
______________ ______________

OTHER

______________ ______________
______________ ______________
______________ ______________
______________ ______________

GEOLOGY

SITE GEOLOGY

Dam ______________
____
____

Spillway ______________
____
____

Outlet works ______________
____
____

GEOLOGY–Continued

SITE GEOLOGY–Continued

Abutments	Left	Right
	________	________
	________	________
	________	________
	________	________
Joint patterns	________	________

Reservoir ________________

____

____

SEEPAGE

Damsite ________________

____

____

Downstream channel ________________

____

____

Other ________________

____

____

PHYSICAL FEATURES

Faulting ________________

____

____

Clay seams ________________

____

____

Depressions ________________

____

____

Sinkholes ________________

____

____

Bedding planes ________________

____

____

Shear seams ________________

____

____

GEOLOGY–Continued

PHYSICAL FEATURES–Continued

Solutioning ______________________________

Other ______________________________

SEISMICITY

Surface rupture ______________________________

Ground tilting ______________________________

Liquefaction potential ______________________________

Settlement ______________________________

Seiches ______________________________

LANDSLIDES

Reservoir ______________________________

Damsite ______________________________

Downstream channel ______________________________

Other ______________________________

CHECKLIST FOR EXAMINATION OF CONCRETE DAM

DAM

UPSTREAM FACE ____________________

DOWNSTREAM FACE ____________________

General condition ____________________
Seepage ____________________

CREST

Offsets ____________________
Roadway ____________________
Walks ____________________
Parapet wall ____________________
Lighting, etc. ____________________

GALLERIES

Concrete ____________________
Metalwork ____________________
Electrical ____________________
Ventilation ____________________
Seepage ____________________
Drains and drainage (all drains should be open) ____________________

Frequency of cleaning or probing ____________________

FOUNDATION TUNNELS

General ____________________
Seepage ____________________

DAM–Continued

INSTRUCTIONS

Structural ______________________
Seepage ______________________

ICE-PREVENTION SYSTEM ______________________

OTHER

______________________ ______________________
______________________ ______________________
______________________ ______________________
______________________ ______________________

ABUTMENTS

	Left	Right
FOUNDATION AT DOWNSTREAM TOE OF DAM	________	________
Leakage around dam	________	________
Location	________	________
Amount	________	________
Measurement methods	________	________
Joint patterns	________	________

OTHER

______________________ ______________________
______________________ ______________________
______________________ ______________________
______________________ ______________________

SPILLWAY

CONTROL STRUCTURES

Crest ____________________
Orifices ____________________

GATES AND CONTROLS

Type of gate ____________________
General condition ____________________
Protective coatings ____________________
Leakage (closed) ____________________
Exercising frequency ____________________
Operation of gates at
time of examination ____________________

CONTROLS FOR GATES

Mechanical

Hoists ____________________
Wire ropes ____________________
Protective coatings ____________________

Electrical

Remote control ____________________
Power supply ____________________
Standby power ____________________
Operation instructions ____________________

WEATHER DOORS

General condition ____________________
Protective coating ____________________
Exercising frequency ____________________
Operation at time
of examination ____________________

SPILLWAY–Continued

CONTROLS FOR WEATHER DOORS

Mechanical

- Hoists ______________________
- Wire ropes ______________________
- Protective coatings ______________________

Electrical ______________________

STOPLOGS

General condition ______________________
Protective coating ______________________
Seals ______________________

STILLING BASIN

Walls ______________________
Floor ______________________
Weir ______________________
River channel below basir

- Riprap ______________________
- Erosion ______________________
- Vegetation ______________________

CHUTE OR TUNNEL

Debris ______________________
Walls

- Surface condition ______________________
- General condition of concrete ______________________
- Movement (offsets) ______________________
- Settlement ______________________
- Joints ______________________
- Cracks or areas of distress ______________________
- Condition of backfill ______________________

Floor

- Surface condition ______________________
- General condition of concrete ______________________

CHUTE OR TUNNEL–Continued

- Movement ____________________
- Settlement ____________________
- Joints ____________________
- Drains ____________________
- Cracks ____________________

OTHER

____________________ ____________________
____________________ ____________________
____________________ ____________________
____________________ ____________________

OUTLET WORKS

INTAKE

- Trashrack ____________________
- Concrete ____________________

OUTLET CONDUIT

- Metalwork ____________________
- Cavitation ____________________

CONTROL FACILITIES

- Gatehouse ____________________
- Crane ____________________
- Gate and controls
  - General condition ____________________
  - Protective coatings ____________________
  - Cavitation ____________________
  - Exercising frequency ____________________
  - Operation at time of examination ____________________
  - Control system
    - Remote ____________________
    - Auxiliary power ____________________
    - Mechanical ____________________

OUTLET WORKS–Continued

CONTROL FACILITIES–Continued

Electrical ______
Operating instructions ______

Weather barrier

General condition ______
Protective coating ______
Exercising frequency ______
Operation at time of examination ______
Control ______

Bulkhead

Availability ______
General condition ______
Protective coating ______
Seals ______

STILLING BASIN

Debris in basin ______
Walls

Surface condition ______
Concrete ______
Joints ______
Cracks ______
Backfill ______
Movement ______

Floor (if visible)

Surface condition ______
Stainless steel liner ______
Concrete ______
Joints ______
Signs of deterioration ______
Cracks ______
Cavitation ______
Movement ______

OUTLET WORKS–Continued

OUTLET CHANNEL

Vegetation ____________
Gravel bars, etc. ____________
Riprap ____________
Stability of side slopes ____________

OTHER

____________ ____________
____________ ____________
____________ ____________
____________ ____________

POWER FEATURES

(If related to safe operation or structural integrity of dam)

INTAKE STRUCTURE ____________

TRASHRACK ____________

BULKHEAD GATE ____________

INTAKE GATES ____________

INTAKE GATE HOISTS ____________

GANTRY CRANE

Mechanical ____________
Electrical ____________
Paint ____________
Operating instructions ____________
Operation during examination ____________
Storage area ____________

PENSTOCK

Powerplant structure ____________
Ceilings ____________
Deck ____________

POWER FEATURES–Continued

PENSTOCK–Continued

Walls ______________________
Substructure ______________________

TAILRACE

Draft tube closure structure ______________________
Draft tube bulkhead ______________________
Gantry crane ______________________

STANDBY POWER UNIT

Condition ______________________
Exercising frequency ______________________
Automatic features ______________________
Operation during examination ______________________

OTHER

______________________ ______________________
______________________ ______________________
______________________ ______________________
______________________ ______________________

RESERVOIR

LOG BOOM ______________________

RESERVOIR LEVEL GAGE

____
____

LANDSLIDES ______________________

(Individual designation, ______________________
location for identification, ______________________
and description) ______________________
____
____
____
____
____

RESERVOIR–Continued

OTHER

______________________ ______________________
______________________ ______________________
______________________ ______________________
______________________ ______________________

ACCESS ROAD

CONDITION OF PAVEMENT ______________________

DITCHES ______________________

BRIDGE

General condition ______________________
Vegetation at abutments and piers ______________________
Bridge supports

- Foundations ______________________
- Substructures–piers ______________________
- Bridge bearings ______________________
- Moving parts ______________________
- Accumulation of birds' nests, etc. ______________________
- Visual examination of scour protection ______________________
- Protective coatings ______________________

Main supporting members

- Deteriorated and/or damaged members ______________________
- Protective coatings ______________________

Bridge deck

- General condition ______________________
- Drainage ______________________
- Expansion joints ______________________

ACCESS ROAD–Continued

BRIDGE–Continued

Guardrails ____________
Signing ____________
Live load capacity ____________

LOSS POTENTIAL (During Emergency)

OTHER

GEOLOGY

SITE GEOLOGY

Dam ____________

Spillway ____________

Outlet works ____________

Abutments	Left	Right
Joint patterns		

Reservoir ____________

GEOLOGY–Continued

SEEPAGE

Damsite

Downstream channel

Other

PHYSICAL FEATURES

Faulting

Clay seams

Depressions

Sinkholes

Bedding planes

Shear seams

Solutioning

Other

SEISMICITY

Surface rupture

Ground tilting

GEOLOGY–Continued

SEISMICITY–Continued

Liquefaction potential

Settlement

Seiches

LANDSLIDES

Reservoir

Damsite

Downstream channel

Other

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Mission

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.