GUIDELINES FOR

SAFETY INSPECTION OF DAMS

Report R92

State of Hawaii

DEPARTMENT OF LAND AND NATURAL RESOURCES

Division of Water and Land Development

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DEPARTMENT OF LAND AND NATURAL RESOURCES
Division of Water and Land Development
State of Hawaii

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PREFACE

The recommended guidelines for the safety inspection of dams were prepared to outline principal factors to be weighed in the determination of existing or potential hazards and to define the scope of activities to be undertaken in the safety inspection of dams. The establishment of rigid criteria or standards is not intended. Safety must be evaluated in the light of peculiarities and local conditions at a particular dam and in recognition of the many factors involved, some of which may not be precisely known. This can only be done by competent, experienced engineering judgement, which the guidelines are intended to supplement and not supplant. The guidelines are intended to be flexible, and the proper flexibility must be achieved through the employment of experienced engineering personnel.

Conditions found during the investigation which do not meet guideline recommendations should be assessed by the investigator as to their importance from the standpoint of the involved degree of risk. Many deviations will not compromise project safety and the investigator is expected to identify them in this manner if that is the case. Others will involve various degrees of risk, the proper evaluation of which will afford a basis for priority of subsequent attention and possible remedial action.

The guidelines present procedures for investigating and evaluating existing conditions for the purpose of identifying deficiencies and hazardous conditions and do not encompass in scope the engineering which will be required to perform the design studies for corrective modification work.

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CHAPTER I

INTRODUCTION

Purpose

The principal purpose of periodic dam safety inspections is to determine that all structural and operational aspects of the dam and its component parts are functioning safely in accordance with the design, established standards, and acceptable practices. The immediate objective is to encourage high safety standards and to influence public and private dam owners to be more safety conscious. In the interest of public safety and of extending the useful life of dam structures, these guidelines present instructions and procedures for safety inspections of dams in the State of Hawaii.

Authority

The Federal Dam Inspection Act, Public Law 92-367, August 1972, authorized the Secretary of the Army, through the Corps of Engineers, to initiate a program of Safety Inspection of Dams throughout the United States.

Applicability

The procedures and guidelines outlined in this document apply to the inspection and evaluation of all dams as defined in the Federal Dam Inspection Act, Public Law 92-367. Included in this program are all artificial barriers together with appurtenant works which impound or divert water and which (1) are twenty-five feet or more in height or (2) have an impounding capacity of fifty acre-feet or more. Not included are barriers which are six feet or less in height, regardless of storage capacity, or barriers which have a storage capacity at maximum water storage elevation of fifteen acre-feet or less regardless of height.

Public Law 92-367 provided the impetus for the Department of Land and Natural Resources' (DLNR) successful campaign, advocating passage of a dam safety law before the Hawaii State Legislature. Public Law 92-367 also provided the authority and funding for the Corps of Engineers, in cooperation with DLNR, to complete an inventory of dams in the State of Hawaii and perform Phase I inspections of 53 non-federal dams in the State of Hawaii between December 1977 and September 1981.

The Federal Water Resources Development Act of 1986, Public Law 99-662 (H.R. 6), November 17, 1986 established the Dam Safety Act of 1986 entitled Title XII - DAM SAFETY appropriating funds to the Secretary of the Army to be distributed to the States establishing a dam safety program.

Pursuant to Act 179D, Session Laws of Hawaii 1987, the Department of Land and Natural Resources adopted Hawaii Administrative Rules, Title 13, Department of Land and Natural Resources, Sub-Title 7-Water and Land Development, Chapter 190 "DAMS AND RESERVOIRS". It was signed by Governor John Waihee on April 9, 1990, and became effective on April 19, 1990.

Chapter 190 - "DAMS AND RESERVOIRS" placed the supervision and safety of all dams and reservoirs larger than a specified minimum size under the jurisdiction of the Department of Land and Natural Resources. Federal dams are exempt from these Rules. These Hawaii Administrative Rules are administered by the Department through the Division of Water and Land Development (DOWALD). The Division inspects, monitors, and evaluates dams currently in service on a five year cycle, or more frequently as necessary to assure safety.

Guidelines for Safety Inspection of Dams is a result of the Dam Safety Act. These guidelines provide professional personnel with a comprehensive guide to a program of dam safety examination and evaluation. It also points out the importance of specialized training and to stimulate wider use of technically trained and experienced consultants.

CHAPTER II

GENERAL REQUIREMENTS

Classification of Dams

Dams are classified in accordance with size and hazard potential in order to formulate a priority basis for selecting dams to be included in the inspection program and also to provide compatibility between guideline requirements and involved risks. When possible, the initial classifications should be based upon information listed in the "National Inventory of Dams Methodology" FEMA-210/April 1991 (Federal Agency Manual) with respect to size, impoundment capacity and hazard potential. It may be necessary to reclassify dams when additional information becomes available.

Size

The classification for size is based on the height of the dam and storage capacity in accordance with Table 1. The height of the dam is established with respect to the maximum storage potential measured from the natural bed of the stream or watercourse at the downstream toe of the barrier, or if it is not across a stream or watercourse, the height from the lowest elevation of the outside limit of the barrier, to the maximum water storage elevation. For the purpose of determining project size, the maximum storage elevation may be considered equal to the top of dam elevation. Size classification may be determined by either storage or height, whichever gives the larger size category.

TABLE 1

SIZE CLASSIFICATION

Category	Impoundment Storage (Acre-Ft.)	Impoundment Height (Ft.)
Small	< 1000 and ≥ 50	< 40 and ≥ 25
Intermediate	≥ 1000 and $< 50{,}000$	≥ 40 and < 100
Large	$\geq 50{,}000$	≥ 100

Hazard Potential

The classification for potential hazards should be in accordance with Table 2. The hazards pertain to potential loss of human life or property damage in the area downstream of the dam in the event of failure or misoperation of the dam or appurtenant facilities. Dams conforming to criteria for the low hazard potential category may damage farm buildings, limited agricultural land, or township and country roads. Significant hazard potential category structures will be those located in predominantly rural or agricultural areas where failure may damage isolated homes, secondary highways or minor railroads or cause interruption of use or service of relatively important public utilities. Dams in the high hazard potential category will be those located where failure may cause serious damage to homes, extensive agricultural, industrial and commercial facilities, important public utilities, main highways, or railroads.

TABLE 2

HAZARD POTENTIAL CLASSIFICATION

Category	Loss of Life (Extent of Development)	Economic Loss (Extent of Development)
Low	None expected (No permanent structures for human habitation)	Minimal (Undeveloped to occasional structures or agriculture)

Significant	Few (No urban developments and no more than a small number of inhabitable structures)	Appreciable (Notable agriculture, industry or structures)
High	More than a few	Extensive community, industry or agriculture

Selection of Dams to be Investigated

The selection of dams to be investigated should be based upon an assessment of existing developments in flood hazard areas. Those dams possessing a hazard potential classified high or significant as indicated in Table 2 should be given first and second priorities, respectively, in the inspection program. Inspection priorities within each category may be developed from a consideration of factors such as size classification and age of the dam, the population size in the downstream flood area, and potential developments anticipated in flood hazard areas.

An initial site visit should be made for those dams lacking any hazard rating. The initial visit should consist of a visual reconnaissance to observe the crest, spillway, any appurtenant structures, and general condition of the dam. This will provide an opportunity to observe flood hazard potential downstream, allow classification of hazard potential, and determine the type of dam safety inspection required.

Types of Dam Safety Inspections

The type of inspection to be conducted will depend on the purpose of the inspection. Dam safety inspections are conducted to determine the status of a dam and its features relative to its structural and operational safety. Five general types of dam safety inspections have been found valuable to assess the condition of the various structures and equipment at a dam site.

1. Formal Dam Safety Inspection

    A. Phase I Investigation

    B. Phase II Investigation

2. Periodic or Intermediate Dam Safety Inspection

3. Routine or Informal Dam Safety Inspection

4. Special Inspection

5. Emergency Inspection

A formal inspection is performed by a team of trained multi-disciplined engineers and a geologist. Design and construction data are evaluated relative to current criteria or the state-of-the-art in order to identify:

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

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

After reviewing and evaluating the records, this experienced team conducts a thorough and comprehensive onsite inspection of all features at the dam site.

Chapters III and IV, covering Phase I and Phase II investigations, will provide detailed descriptions of recommended guidelines for dam safety inspections.

Periodic or intermediate dam safety inspections are usually conducted between formal inspections. A periodic or intermediate dam safety inspection differs from a formal inspection because while all available data are reviewed (in order to become thoroughly familiar with the dam and its features), they are not compared to the current state-of-the-art. The data review focuses on the current status of the dam and its features. After reviewing this data, a comprehensive visual onsite inspection is conducted; however, all of the mechanical equipment may not be test operated during any inspection. An alternate schedule to test operate equipment may be set up whereby certain equipment are tested during one inspection, and the remaining equipment is tested at another time or during the next scheduled inspection.

A routine or informal dam safety inspection is most typically conducted by field or operating personnel while performing a work task such as operations, maintenance, or structural behavior monitoring. The primary focus is on the current conditions of the dam and its features. Personnel at the dam site should be prompted to be observant of the condition of the various features of the dam and appurtenances adjacent to his/her worksite. Any unusual occurrences such as strange noises or changes in visual appearance should be reported to a responsible employee such as a supervisor.

Special inspections are performed generally by an experienced engineer or geologist whenever a particular feature of a dam that is not normally inspected becomes available for inspection due to circumstances, such as low reservoir level or dewatering of an outlet works conduit.

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

Qualifications of Inspection Team

The type of inspection to be performed will usually affect the number and required expertise of individuals who participate in the dam safety inspection. Engineers and geologists who are selected to participate as a team in the inspection phase should have sufficient technical knowledge and experience to critically assess the adequacy of design, construction, and performance of dams during both past and anticipated events. These team members should be selected based on their capability to assess the complexities of the designated dam. Field personnel familiar with the subject dam and appurtenances should accompany the team during the onsite examination to answer questions concerning the condition and the operation and maintenance of the various features, and to operate the equipment.

The initial or formal investigations should be conducted under the direction of a licensed professional Civil Engineer with team members who are experienced in the investigation, design, construction and operation of dams, applying the disciplines of hydrologic, hydraulic, soils and structural engineering and engineering geology. Team members may include geologists, geotechnical, structural, electrical, mechanical, and hydraulic engineers as well as an instrumentation specialist. Hydrologic and hydraulic studies may be performed by special consultants who may not necessarily participate in the field inspections.

Periodic or intermediate investigations should be conducted under the direction of a licensed professional Civil Engineer along with team members similarly experienced as in initial or formal investigations.

Routine or informal dam safety inspections may be conducted by either a Civil Engineer or technicians familiar with dam safety inspections, including various dam personnel.

Personnel for special inspections will be based on the objectives of the inspection, and may include one or more individuals in civil, mechanical, geotechnical, structural, electrical, hydraulics engineering, geologist, or instrumentation specialist.

Depending on the urgency and reason for the inspection, emergency inspections may include one or more individuals in civil, mechanical, geotechnical, structural, electrical, hydraulics engineering, geologist, or instrumentation specialist.

CHAPTER III

PHASE I INVESTIGATION

Purpose

The primary purpose of the Phase I investigation program is to identify expeditiously those dams which may pose hazards to human life or property. Inspection activities provide the basis for dam inventories, correlation of plans with actual construction, safety evaluation of existing dams, evaluation of downstream hazards, and emergency response capability. Adequate inspection and documentation are necessary before enforcement actions can be taken.

Scope

The Phase I investigation will develop an assessment of the general condition with respect to safety of the project based upon available data and a visual inspection, determine any need for emergency measures and conclude if additional studies, investigation and analyses are necessary and warranted. A review will be made of pertinent existing and available engineering data relative to the design, construction and operation of the dam and appurtenant structures, including electrical and mechanical operating equipment and measurements from inspection and performance instruments and devices; and a detailed systematic visual inspection will be performed of those features relating to the stability and operational adequacy of the project. Based upon findings of the review of engineering data and the visual inspection, an evaluation will be made of the general condition of the dam, including where possible the assessment of the hydraulic and hydrologic capabilities and the structural stability.

Documentation

Because the inspection program will provide the basis for enforcement action and some protection in terms of legal liability, adequate documentation of inspections is necessary.

1. Written documentation of visual inspections may be provided to the files and dam owners upon request. Inspection reports should detail all visual observations of embankment, spillway, and reservoir conditions at the time of inspection. Any recommendations to or verbal agreements with the owner/operator should be placed in writing without delay.
2. Photographs of the dam and specific observations or problem areas must be filled with site name and date of inspection clearly marked. All negatives must be carefully labeled and preserved in anticipation of possible enforcement action.
3. Any other conversation on-site or by telephone with the owner, owner's agent, consulting engineer, attorney, or concerned citizen should be documented in the file.
4. Any legal notice or order must clearly follow all legal requirements of the statute.

Engineering Data

To the extent feasible, the engineering data listed in Appendix A relating to the design, construction, and operation of the dam and appurtenant structures, should be collected from existing records and reviewed to aid in evaluating the adequacy of hydraulic and hydrologic capabilities and stability of the dam. Where the necessary engineering data are unavailable, inadequate or invalid, a listing should be made of those specific additional data deemed necessary by the engineer in charge of the investigation and included in the Phase I report.

Field Inspections

The field inspection of the dam, appurtenant structures, reservoir area, and downstream channel in the vicinity of the dam should be conducted in a systematic manner to minimize the possibility of any significant feature being overlooked. A detailed checklist should be developed and followed for each dam inspected to document the examination of each significant structural and hydraulic feature including electrical and mechanical equipment for operation of the control facilities that affect the safety of the dam.

Particular attention should be given to detecting evidence of leakage, erosion, seepage, slope instability, undue settlement, displacement, tilting, cracking, deterioration, and improper functioning of drains and relief wells. The adequacy and quality of maintenance and operating procedures as they pertain to the safety of the dam and operation of the control facilities should also be assessed.

Inspections made during construction may provide verification that dams are built in accordance with approved plans and specifications. Often the most vulnerable phase in the life of a structure is the construction phase. Cofferdams, diversions, and the main embankment are usually incapable of safely passing floods until sufficient dam height is achieved. An emergency action plan specific to construction activities should be approved prior to starting the project. Inspectors should ask on-site monitoring personnel to produce their copy of the plan and explain emergency procedures. The entire site should be examined to check conformity with the approved plans and specifications, and applicable safety precautions.

Photographs and drawings should be used freely to record conditions in order to minimize descriptions.

The field inspection should include appropriate features and items, including but not limited to those listed in Appendix B, which may influence the safety of the dam or indicate potential hazards to human life or property.

Evaluation of Hydraulic and Hydrologic Features

Design Data

Original hydraulic and hydrologic design assumptions obtained from the project records should be assessed to determine their acceptability in evaluating the safety of the dam. All constraints on water control such as blocked entrances, restrictions on operation of spillway and outlet gates, inadequate energy dissipators or restrictive channel conditions, significant reduction in reservoir capacity by sediment deposits and other factors should be considered in evaluating the validity of discharge ratings, storage capacity, hydrographs, routings and regulation plan. The discharge capacity and/or storage capacity should be capable of safely handling the recommended spillway design flood for the size and hazard potential classification of the dam as indicated in Table 3. The hydraulic and hydrologic determinations for design as obtained from project records will be acceptable if conventional techniques similar to the procedures outlined in the Hydraulic and Hydrologic Analysis paragraph (Chapter IV), were used in obtaining the data. When the project design flood actually used exceeds the recommended spillway design flood, from Table 3, the project design flood will be acceptable in evaluating the safety of the dam.

TABLE 3

HYDROLOGIC EVALUATION GUIDELINES

RECOMMENDED SPILLWAY DESIGN FLOODS

Hazard	Size	*Spillway Design Flood (SDF)
Low	Small	50 to 100-yr frequency
	Intermediate	100-yr to 1/2 PMF
	Large	1/2 PMF to PMF
Significant	Small	100-yr to 1/2 PMF
	Intermediate	1/2 PMF to PMF
	Large	PMF
High	Small	1/2 PMF to PMF
	Intermediate	PMF
	Large	PMF

* The recommended design floods in this column represent the magnitude of the spillway design flood (SDF), which is intended to represent the largest flood that need be considered in the evaluation of a given project, regardless of whether a spillway is provided; i.e., a given project should be capable of safely passing the appropriate SDF. Where a range of SDF is indicated, the magnitude that most closely relates to the involved risk should be selected.

100-yr = 100-Year Exceedence Interval. The flood magnitude expected to be exceeded, on the average, of once in 100 years. It may also be expressed as an exceedence frequency with a one-percent chance of being exceeded in any given year.

PMF = Probable Maximum Flood. The flood that may be expected from the most severe combination of critical meteorologic and hydrologic conditions that are reasonably possible in the region. The PMF is derived from probable maximum precipitation (PMP), which information is generally available from the National Weather Service, NOAA. Most Federal agencies apply reduction factors to the PMP when appropriate. Reductions may be applied because rainfall isohyetals are unlikely to conform to the exact shape of the drainage basin and/or the storm is not likely to center exactly over the drainage basin. In some cases, local topography will cause changes from the generalized PMP values, therefore, it may be advisable to contact Federal construction agencies to obtain the prevailing practice in specific areas.

Experience Data

In some cases where design data are lacking, an evaluation of overtopping potential may be based on watershed characteristics and rainfall and reservoir records. An estimate of the probable maximum flood may also be developed from a conservative, generalized comparison of the drainage area size and the magnitude of recently adopted probable maximum floods for dam sites in comparable hydrologic regions. Where the review of such experience data indicates that the recommended spillway design flood would not cause overtopping, additional hydraulic and hydrologic determinations will be unnecessary.

Evaluation of Structural Stability

The Phase I evaluations of structural adequacy of project features are expected to be based principally on existing conditions as revealed by the visual inspection, together with available design and construction information and records of performance. The objectives are to determine the existence of conditions which are hazardous, or which with time might develop into safety hazards, and formulate recommendations pertaining to the need for any additional studies, investigation, or analyses. The results of this phase of the inspection must rely substantially upon the experience and judgement of the inspecting engineer.

Design and Construction Data

The principal design assumptions and analyses obtained from the project records should be assessed. Original design and construction records should be used judiciously, recognizing the restricted applicability of such data as material strengths and permeabilities, geological factors and construction descriptions. Original stability studies and analyses should be acceptable if conventional techniques and procedures similar to those outlined in the Stability Investigations paragraph (Chapter IV) were employed, provided that review of operational and performance data confirm that the original design assumptions were adequately conservative. The need for such analyses where either none exist or the originals are incomplete or unsatisfactory will be determined by the inspecting engineer based upon other factors such as condition of structures, prior maximum loadings and the hazard degree of the project. Design assumptions and analyses should be on record for all dams in the high hazard category and large dams in the significant hazard category. This requirement for other dams will be subject to the opinion of the inspecting engineer.

Operating Records

The performance of structures under prior maximum loading conditions should in some instances provide partial basis for stability evaluation. Satisfactory experience under loading conditions not expected to be exceeded in the future should generally be indicative of satisfactory stability, provided adverse changes in physical conditions have not occurred. Instrumentation observations of forces, pressures, loads, stresses, strains, displacements, deflections or other related conditions should also be utilized in the safety evaluation. Where such data indicate abnormal behavior, unsafe movement or deflections, or loadings which adversely affect the stability or functioning of the structure, prompt reporting of such circumstances is required without the delay for preparation of the official inspection report.

Post Construction Changes

Data should be collected on changes which have occurred since project construction that might influence the safety of the dam such as road cuts, quarries, mining and groundwater changes.

Seismic Stability

An assessment should be made of the potential vulnerability of the dam to seismic events and a recommendation developed with regard to the need for additional seismic investigation. In general, projects located in Seismic Zones 0, 1, and 2 may be assumed to present no hazard from earthquake provided static stability conditions are satisfactory and conventional safety margins exist. Dams in Zones 3 and 4 should, as a minimum, have on record suitable analyses made by conventional equivalent static load methods. The seismic zones together with appropriate coefficients for use in such analyses are shown in Figure 1. Boundary lines are approximate and in the event of doubt about the proper zone, the higher zone should be used. All high hazard category dams in Zone 4 and high hazard dams of the hydraulic fill type in Zone 3 should have a stability assessment based upon knowledge of regional and local geology, engineering seismology, in-situ properties of materials and appropriate dynamic analytical and testing procedures. The assessment should include the possibility of physical displacement of the structures due to movements along active faults. Departure from this general guidance should be made whenever in the judgement of the investigating engineer different seismic stability requirements are warranted because of local geological conditions or other reasons.

CHAPTER IV

PHASE II INVESTIGATION

Purpose

The Phase II investigation will be supplementary to Phase I and should be conducted when the results of the Phase I investigation indicate the need for additional in-depth studies, investigations or analyses.

Scope

The Phase II investigation should include all additional studies, investigations and analyses necessary to evaluate the safety of the dam. Included, as required, will be additional visual inspections, measurements, foundation exploration and testing, materials testing, hydraulic and hydrologic analyses and structural stability analysis.

Hydraulic and Hydrologic Analyses

Hydraulic and hydrologic capabilities should be determined using the following criteria and procedures. Depending on the project characteristics, either the spillway design flood peak inflow or the spillway design flood hydrograph should be the basis for determining the maximum water surface elevation and maximum outflow. If the operation or failure of upstream water control projects would have significant impact on peak flow or hydrograph analyses, the impact should be assessed.

Maximum Water Surface Based on SDF Peak Inflow

When the total project discharge capability at maximum pool exceeds the peak inflow of the recommended SDF, and operational constraints would not prevent such a release at controlled projects, a reservoir routing is not required. The maximum discharge should be assumed equal to the peak inflow of the spillway design flood. Flood volume is not controlling in this situation, and surcharge storage is either absent or is significant only to the extent that it provides the head necessary to develop the release capability required.

Peak for 100-Year Flood

When the 100-year flood is applicable under the provisions of Table 3 and data are available, the spillway design flood peak inflow may be determined by use of "A Uniform Technique for Determining Flood Frequencies," Water Resources Council (WRC), Hydrology Committee, Bulletin 15, December 1967. Flow frequency information from regional analysis is generally preferred over single station results when available and appropriate. Rainfall-runoff techniques may be necessary when there are inadequate runoff data available to make a reasonable estimate of flow frequency.

Peak for PMF or Fraction Thereof

When either the Probable Maximum Flood peak or a fraction thereof is applicable under the provisions of Table 3, the unit hydrograph - infiltration loss technique is generally the most expeditious method of computing the spillway design flood peak for most projects. This technique is discussed in the following paragraph.

Maximum Water Surface Based on SDF Hydrograph

Both peak and volume are required in this analysis. Where surcharge storage is significant, or where there is insufficient discharge capability at maximum pool to pass the peak inflow of the SDF, considering all possible operational constraints, a flood hydrograph is required. When there are upstream hazard areas that would be imperiled by fast rising reservoir levels, SDF hydrographs should be routed to ascertain available time for warning and escape. Determination of probable maximum precipitation or 100-year precipitation, whichever is applicable, and unit hydrographs or runoff models will be required, followed by the determination of the PMF or 100-year flood. Conservative loss rates (significantly reduced by antecedent rainfall conditions where appropriate) should be estimated for computing the rainfall excess to be utilized with unit hydrographs. Rainfall values are usually arranged with gradually ascending and descending rates with the maximum rate late in the storm. When applicable, conservatively high snowmelt runoff rates and appropriate releases from upstream projects should be assumed. The PMF may be obtained from State of Hawaii Department of Land and Natural Resources, Division of Water and Land Development (DLNR/DOWALD) publications such as "Rainfall Frequency Study for Oahu", Report R-73; and "Rainfall Atlas of Hawaii," Report R-76 in 1986; and "Rainfall-Frequency Atlas of the Hawaiian Islands", Technical Paper No. 43, published by Weather Bureau, Dept. of Commerce, Washington D.C. in 1962. The maximum water surface elevation and spillway design flood outflow are then determined by routing the inflow hydrograph through the reservoir surcharge storage, assuming a starting water surface at the bottom of surcharge storage, or lower when appropriate. For projects where the bottom of surcharge space is not distinct, or the flood control storage space (exclusive of surcharge) is appreciable, it may be appropriate to select starting water surface elevations below the top of the flood control storage for routings. Conservatively high starting levels should be estimated on the basis of hydrometeorological conditions reasonably characteristic for the region and flood release capability of the project. Necessary adjustment of reservoir storage capacity due to existing or future sediment or other encroachment may be approximated when accurate determination of deposition is not practicable.

Acceptable Procedures

Techniques for performing hydraulic and hydrologic analyses are generally available from publications prepared by Federal agencies involved in water resources development or textbooks written by the academic community. Some of these procedures are rather sophisticated and expensive but more reliable than simplified methods, their use is generally not warranted in studies connected with this program unless they can be performed quickly and inexpensively. There may be situations where the more complex techniques have to be employed to obtain reliable results; however, these cases will be exceptions rather than the rule. Whenever the acceptability of procedures is in question, the advice of competent experts should be sought. Such expertise is generally available in the Corps of Engineers, Bureau of Reclamation and Soil Conservation Service. Many other agencies, educational facilities and private consultants can also provide expert advice. Regardless of where such expertise is based, the qualification of those individuals offering to provide it should be carefully examined and evaluated.

Freeboard Allowances

Guidelines on specific minimum freeboard allowances are not considered appropriate because of the many factors involved in such determinations. The investigator will have to assess the critical parameters for each project and develop its minimum requirement. Many projects are reasonably safe without freeboard allowance because they are designed for overtopping, or other factors minimize possible overtopping. Conversely, freeboard allowances of several feet may be necessary to provide a safe condition. Parameters that should be considered include the duration of high water levels in the reservoir during the design flood; the effective wind fetch and reservoir depth available to support wave generation; the probability of high wind speed occurring from a critical direction; the potential wave runup on the dam based on roughness and slope; and the ability of the dam to resist erosion from overtopping waves.

Stability Investigations

The Phase II stability investigations should be compatible with the guidelines of the following paragraphs.

Foundation and Material Investigations

The scope of the foundation bed materials investigation should be limited to obtaining the information required to analyze the structural stability and to investigate any suspected condition which would adversely affect the safety of the dam. Such investigations may include borings to obtain concrete, embankment, soil foundation, and bedrock samples; testing specimens from these samples to determine the strength and elastic parameters of the materials, including the soft seams, joints, fault gouge and expansive clays or other critical materials in the foundation; determining the character of the bedrock including joints, bedding planes, fractures, faults, voids and caverns, and other geological irregularities; and installing instruments for determining movements, strains, suspected excessive internal seepage pressures, seepage gradients and uplift forces. Special investigations may be necessary where suspect rock types such as limestone, gypsum, salt, basalt, claystone, shales or others are involved in foundations or abutments in order to determine the extent of cavities, piping or other deficiencies in the rock foundation. A concrete core drilling program should be undertaken only when the existence of significant structural cracks is suspected or the general qualitative condition of the concrete is in doubt. The tests of materials will be necessary only where such data are lacking or are outdated.

Stability Assessment

Stability assessments should utilize in-situ properties of the structure and its foundation and pertinent geologic information. Geologic information that should be considered includes groundwater and seepage conditions; lithology, stratigraphy, and geologic details disclosed by borings, "as-built" records, geologic interpretation; maximum past overburden at site as deduced from geologic evidence; slickensides, and field evidence relating to slides, faults, movements and earthquake activity. Foundations may present problems where they contain adversely oriented joints, slickensides or fissured material, faults, seams of soft materials, or weak layers. Such defects and excess pore water pressures may contribute to instability. Special tests may be necessary to determine physical properties of particular materials. The results of stability analyses afford a means of evaluating the structure's existing resistance to failure and also the effects of any proposed modifications. Results of stability analyses should be reviewed for compatibility with performance experience when possible.

Seismic Stability

The inertial forces for use in the conventional equivalent static force method of analysis should be obtained by multiplying the weight by the seismic coefficient and should be applied as a horizontal force at the center of gravity of the section or element. The seismic coefficients suggested for use with such analyses are listed in Figure 1. Seismic stability investigations for all high hazard category dams located in Seismic Zone 4 and high hazard dams of the hydraulic fill type in Zone 3 should include suitable dynamic procedures and analyses. Dynamic analyses for other dams and higher seismic coefficients are appropriate if in the judgment of the investigating engineer they are warranted because of proximity to active faults or other reasons. Seismic stability investigations should utilize "state-of-the-art" procedures involving seismological and geological studies to establish earthquake parameters for use in dynamic testing of materials stability analyses may be based upon either time-history or response spectra techniques. The results of dynamic analyses should be assessed on the basis of whether or not the dam would have sufficient residual integrity to earthquake which might occur near the project location.

Embankment Dams

Liquefaction

The phenomenon of liquefaction of loose, saturated sands and silts may occur when such materials are subjected to shear deformation or earthquake shocks. The possibility of liquefaction must presently be evaluated on the basis of empirical knowledge supplemented by special laboratory tests and engineering judgement. The possibility of liquefaction in sands diminishes as the relative density increases above approximately 70 percent. Hydraulic fill dams in Seismic Zones 3 and 4 should receive particular attention since such dams are susceptible to liquefaction under earthquake shocks.

Shear Failure

Shear failure is one in which a portion of an embankment and foundation moves by sliding or rotating relative to the remainder of the mass. It is conventionally represented as occurring along a surface and is so assumed in stability analyses, although shearing may occur in a zone of substantial thickness. The circular arc or the sliding wedge method of analyzing stability, as pertinent, should be used. The circular arc method is generally applicable to essentially homogenous embankments and to soil foundations consisting of thick deposits of fine-grained soil containing no layers significantly weaker than other strata in the foundation. The wedge method is generally applicable to rockfill dams and to earth dams on foundations containing weak layers. Other methods of analysis such as those employing complex shear surfaces may be appropriate depending on the soil and rock in the dam and foundation. Such methods should be in reputable usage in the engineering profession.

Loading Conditions

The loading conditions for which the embankment structures should be investigated are: (I) Sudden drawdown from spillway crest elevation or top of gates, (II) Partial pool, (III) Steady state seepage from spillway crest elevation or top of gate elevation, and (IV) Earthquake. Cases I and II above apply to upstream slopes only; Case III applies to downstream slopes; and Case IV applies to both upstream and downstream slopes. A summary of suggested strengths and safety factors are shown in Table 4.

TABLE 4

FACTORS OF SAFETY

Case	Loading Conditions	Factor of Safety	Shear Strength [1]	Remarks
I	Sudden drawdown from spillway crest or top of gates to minimum drawdown elevation.	1.2 *	Minimum Composite of R and S shear strengths See Figure 2.	Within the drawdown zone submerged unit weights of materials are used for computing forces resisting sliding and saturated unit weights are used for computing forces contributing to sliding.
II	Partial pool with assumed horizontal steady seepage saturation.	1.5	(R+S)/2 for R<S S for R>S	Composite intermediate envelope of R and S shear strengths. See Figure 3.
III	Steady seepage from spillway crest or top of gates with $K_h/K_v = 9$ assumed**	1.5	Same as Case II	
IV	Earthquake (Cases II and III with seismic loading)	1.5	***	See Figure 1 for Seismic Coefficient.

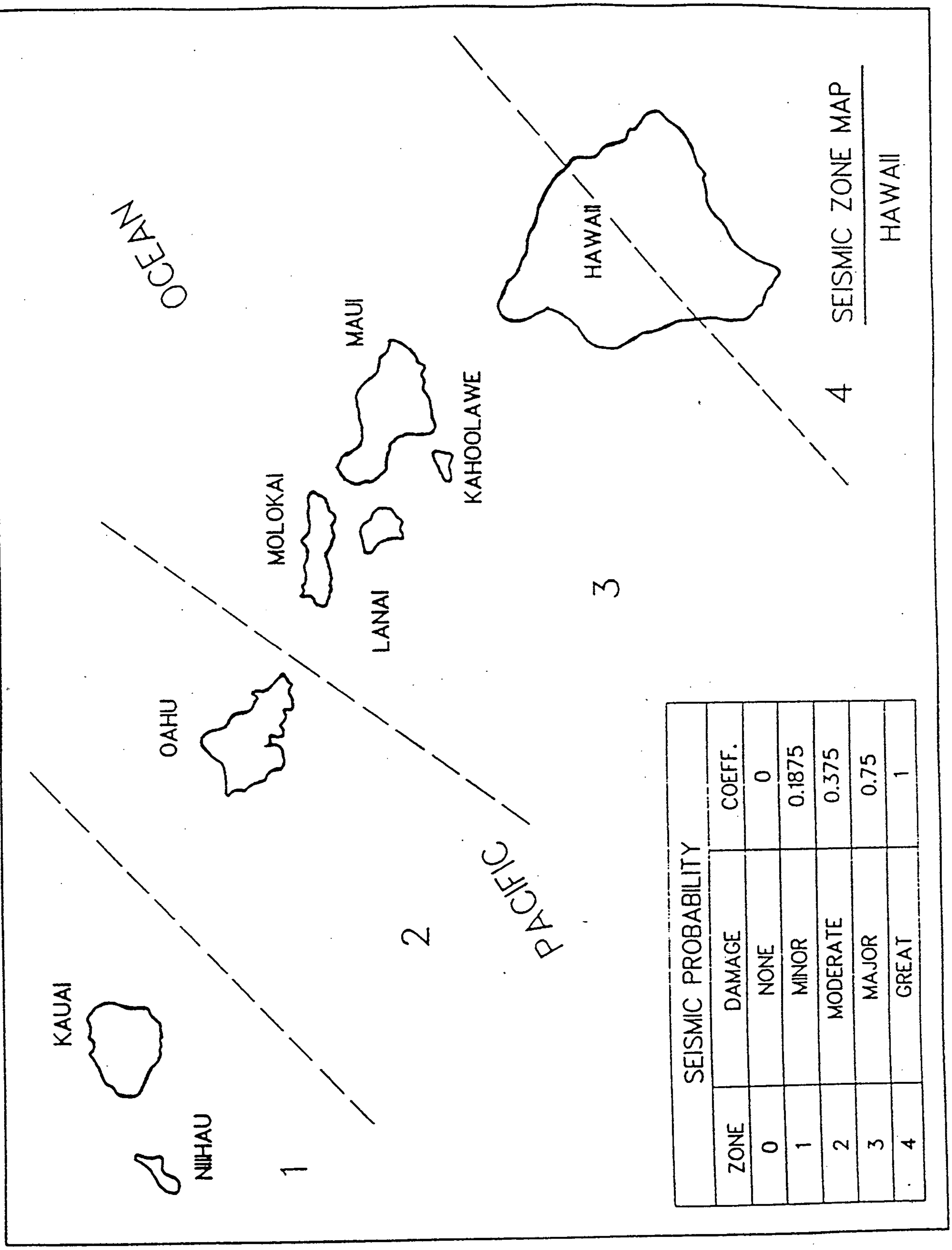
[1] Other strength assumptions may be used if in common usage in the engineering profession.

* The safety factor should not be less than 1.5 when drawdown rate and pore water pressure developed from flow nets are used in stability analyses.

** K_h/K_v is the ratio of horizontal to vertical permeability. A minimum of 9 is suggested for use in compacted embankments and alluvial sediments.

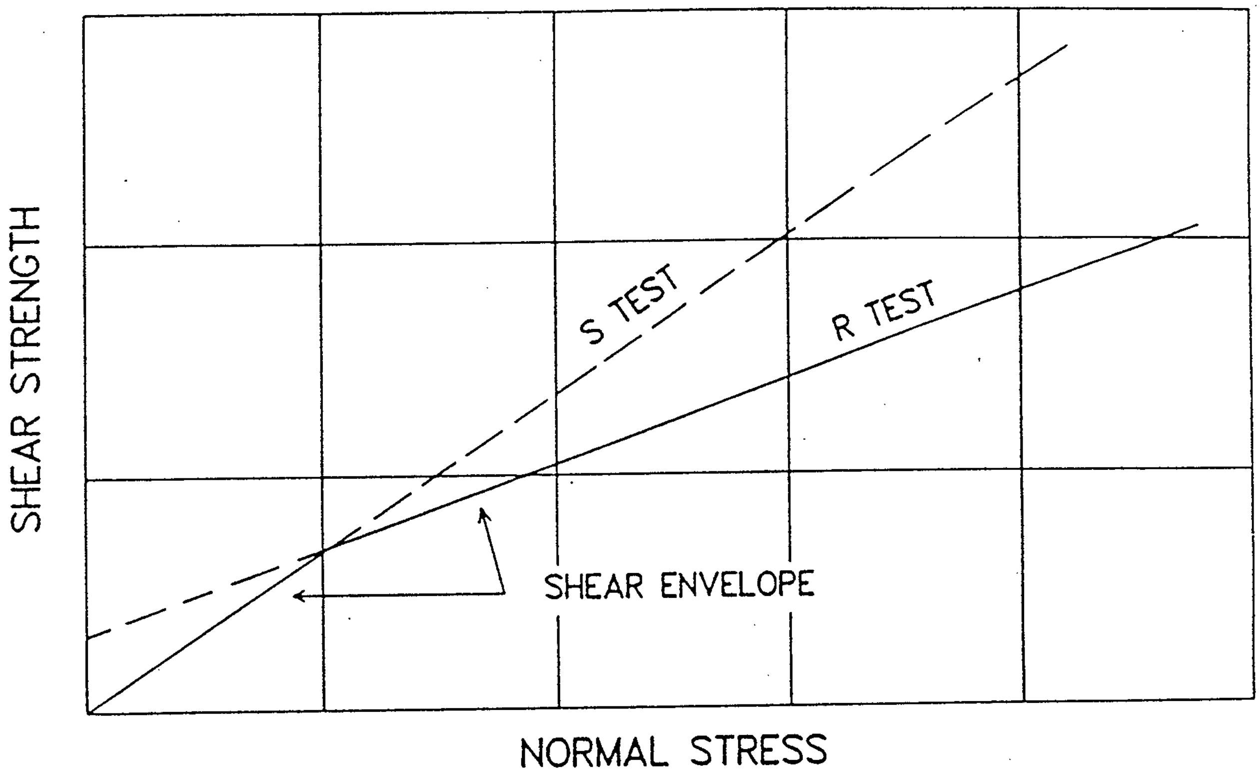
*** Use shear strength for case analyzed without earthquake. It is not necessary to analyze sudden drawdown for earthquake loading. Shear strength tests are classified according to the controlled drainage conditions maintained during the test. R tests are those in which specimen drainage is allowed during consolidation (or swelling) during application of shearing stresses. S tests allow full drainage during initial stress application and shearing is at a slow rate so that complete specimen drainage is permitted during the complete test.

Reference: TM 5-809-10/NAVFAC P-355/AFM 88-3, Chapter 13; February 1983



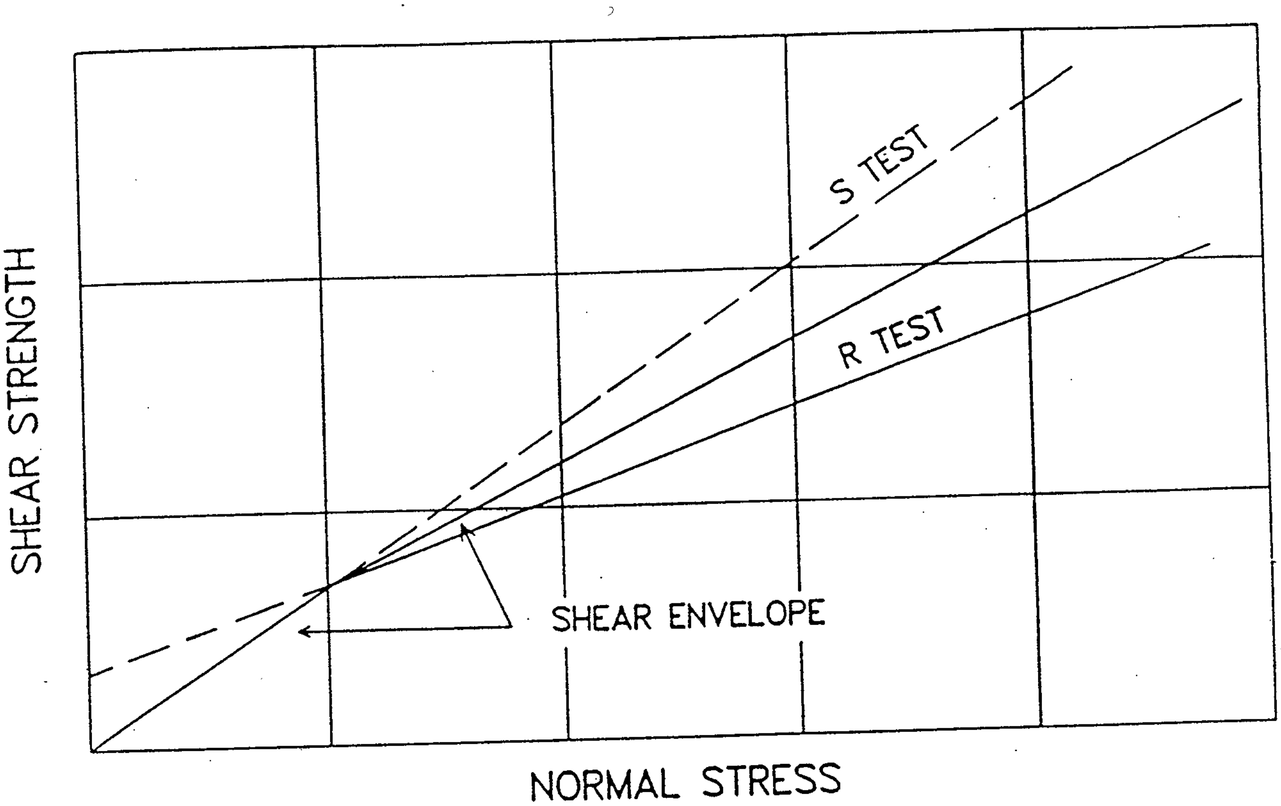
SEISMIC PROBABILITY		
ZONE	DAMAGE	COEFF.
0	NONE	0
1	MINOR	0.1875
2	MODERATE	0.375
3	MAJOR	0.75
4	GREAT	1

Figure 1



SHEAR ENVELOPE FOR CASE I

Figure 2



SHEAR ENVELOPE FOR CASES II AND III

Figure 3

Safety Factors

Safety factors for embankment dam stability studies should be based on the ratio of available shear strength to developed shear strength, S_D:

$$S_D = \frac{C}{(F.S.)} + \frac{\sigma(\tan \phi)}{F.S.}$$

where

C = Cohesion

ϕ = Angle of internal friction

σ = Normal stress

F.S. = Factor of Safety

The factors of safety listed in Table 4 are recommended as minimum acceptable. Final accepted factor of safety should depend upon the degree of confidence the investigating engineer has in the engineering data available to him. The consequences of a failure with respect to human life and property damage are important considerations in establishing factor of safety for specific investigations.

Seepage Failure

A critical uncontrolled underseepage or through seepage condition that develops during a rising pool can quickly reduce a structure which was stable under previous conditions, to a total structural failure. The visually confirmed seepage conditions to be avoided are (1) the exit of the phreatic surface on the downstream slope of the dam, (2) development of hydrostatic heads sufficient to create in the area downstream of the dam sand boils that erode materials by the phenomenon known as "piping", and (3) localized concentrations of seepage along conduits or through pervious zones. The dams most susceptible to seepage problems are those built of or on pervious materials of uniform fine particle size, with no provisions for an internal drainage zone and/or no underseepage controls.

Seepage Analyses

Review and modifications to original seepage design analyses should consider conditions observed in the field inspection and piezometer instrumentation. A seepage analysis should consider the permeability ratios resulting from natural deposition and from compaction placement of materials with appropriate variation between horizontal and vertical permeability. An underseepage analysis of the embankment should provide a critical gradient factor of safety (F.S.), for the maximum head condition of not less than 1.5 in the area downstream of the embankment.

$$F.S. = i_c/i = \frac{H_c/D_b}{H/D_b} = \frac{D_b(\gamma_m - \gamma_w)}{H\gamma_w}$$

where

i_c = Critical gradient

i = Design gradient

H = Uplift head at downstream toe of dam measured above tailwater

H_c = The critical uplift

D_b = The thickness of the top impervious blanket at the downstream toe of the dam

γ_m = The estimated saturated unit weight of the material in the top impervious blanket

γ_w = The unit weight of water

F.S. = Factor of Safety

Where a factor of safety less than 1.5 is obtained, the provision of an underseepage control system is indicated. The factor of safety of 1.5 is a recommended minimum and may be adjusted by the responsible engineer based on the competence of the engineering data.

Concrete Dams and Appurtenant Structures

Requirements for Stability

Concrete dams and structures appurtenant to embankment dams should be capable of resisting overturning, sliding and overstressing with adequate factor of safety for normal and maximum loading conditions.

Loads

Loadings to be considered in stability analyses include the water load on the upstream face of the dam; the weight of the structure; internal hydrostatic pressures (uplift) within the body of the dam, at the base of the dam and within the foundation; earth and silt loads; ice pressure, seismic and thermal loads, and other loads as applicable. Where tailwater or backwater exists on the downstream side of the structure it should be considered, and assumed uplift pressures should be compatible with drainage provisions and uplift measurements if available. Earthquake forces should consist of the inertial forces due to the horizontal acceleration of the dam itself and hydrodynamic forces resulting from the reaction of the reservoir water against the structure. Dynamic water pressures for use in conventional methods of analysis may be computed by means of the "Westergaard Formula" using the parabolic approximation (H.M. Westergaard, "Water Pressures on Dams During Earthquakes," Trans., ASCE, Vol 98, 1933, pages 418-433), or similar method.

Stresses

The analysis of concrete stresses should be based on in-situ properties of the concrete and foundation. Computed maximum compressive stresses for normal operating conditions in the order of 1/3 or less of in-situ strengths should be satisfactory. Tensile stresses in unreinforced concrete should be acceptable only in locations where cracks will not adversely affect the overall performance and stability of the structure. Foundation stresses should be such as to provide adequate safety against failure of the foundation material under all loading conditions.

Overturning

A gravity structure should be capable of resisting all overturning forces. It can be considered safe against overturning if the resultant of all combinations of horizontal and vertical forces, excluding earthquake forces, acting above any horizontal plane through the structure or at its base is located within the middle third of the section. When earthquake is included, the resultant should fall within the limits of the plane or base and foundation pressures must be acceptable. When these requirements for location of the resultant are not satisfied, the investigating engineer should assess the importance to stability of the deviations.

Sliding

Sliding of concrete gravity structures and of abutment and foundation rock masses for all types of concrete dams should be evaluated by the shear-friction resistance concept. The available sliding resistance is compared with the driving force which tends to induce sliding to arrive at a sliding stability safety factor. The investigation should be made along all potential sliding paths. The critical path is that plane or combination of planes which offers the least resistance.

Sliding Resistance

Sliding resistance is a function of the unit shearing strength at no normal load (cohesion) and the angle of friction on a potential failure surface. It is determined by computing the maximum horizontal driving force which could be resisted along the sliding path under investigation. The following general formula is obtained from the principles of statics and may be derived by resolving forces parallel and perpendicular to the sliding plane:

$$R_R = V\tan(\phi + \alpha) + \frac{cA}{\cos\alpha(1 - \tan\phi \tan\alpha)}$$

where

R_R	=	Sliding Resistance (maximum horizontal driving force which can be resisted by the critical path)
ϕ	=	Angle of internal friction of foundation material or, where applicable, angle of sliding friction
V	=	Summation of vertical forces (including uplift)
c	=	Unit shearing strength at zero normal loading along potential failure plane
A	=	Area of potential failure plane developing unit shear strength "c"
α	=	Angle between inclined plane and horizontal (positive for uphill sliding)

For sliding down hill the angle α is negative and the above equation becomes:

$$R_R = V\tan(\phi - \alpha) + \frac{cA}{\cos\alpha(1 + \tan\phi \tan\alpha)}$$

When the plane of investigation is horizontal, and the angle α is zero R_R reduces to the following:

$$R_R = V(\tan\phi) + cA$$

Downstream Resistance

When the base of a concrete structure is embedded in rock or the potential failure plane lies below the base, the passive resistance of the downstream layer of rock may sometimes be utilized for sliding resistance. Rock that may be subjected to high velocity water scouring should not be used. The magnitude of the downstream resistance is the lesser of (a) the shearing resistance along the continuation of the potential sliding plane until it daylights, or (b) the resistance available from the downstream rock wedge along an inclined plane. The theoretical resistance offered by the passive wedge can be computed by a formula equivalent to the formula for R_{R}.:

$$P_p = W\tan(\phi + \alpha) + \frac{cA}{\cos\alpha(1 - \tan\phi\tan\alpha)}$$

where

P_p	=	Passive resistance of rock wedge
W	=	Weight (buoyant weight if applicable) of downstream rock wedge above inclined plane of resistance, plus any superimposed loads
ϕ	=	Angle of internal friction or, if applicable, angle of sliding friction
α	=	Angle between inclined failure plane and horizontal
c	=	Unit shearing strength at zero normal load along failure plane
A	=	Area of inclined plane of resistance

When considering cross-bed shear through a relatively shallow, competent rock strut, without adverse jointing or faulting, W and α may be taken at zero and 45°, respectively, and an estimate of passive wedge resistance per unit width obtained by the following equation:

$$P_p = 2cD$$

where

$$D = \text{Thickness of the rock strut}$$

Safety Factor

The shear-friction safety factor is obtained by dividing the resistance R_R by H, the summation of horizontal service loads to be applied to the structure:

$$S_{s\text{-}f} = \frac{R_R}{H}$$

When the downstream passive wedge contributes to the sliding resistance, the shear-friction safety factor formula becomes:

$$S_{s\text{-}f} = \frac{R_R + P_p}{H}$$

The above direct superimposition of passive wedge resistance is valid only if shearing rigidities of the foundation components are similar. Also, the compressive strength and buckling resistance of the downstream rock layer must be sufficient to develop the wedge resistance. For example, a foundation with closely spaced, near horizontal, relatively weak seams might not contain sufficient buckling strength to develop the magnitude of wedge resistance computed from the cross-bed shear strength. In this case, wedge resistance should not be assumed without resorting to special treatment (such as installing foundation anchors). Computed sliding safety factors approximating 3 or more for all loading conditions without earthquake, and 1.5 including earthquake, should indicate satisfactory stability, depending upon the reliability of the strength parameters used in the analyses. In some cases when the results of comprehensive foundation studies are available, smaller safety factors may be acceptable. The selection of shear strength parameters should be fully substantiated. The basis for any assumptions; the results of applicable testing, studies and investigations; and all pre-existing, pertinent data should be reported and evaluated.

CHAPTER V

REPORTS

General

This chapter outlines the procedures for reporting the results of the different types of dam safety inspections. Hazardous conditions should be reported immediately upon detection to the owner of the dam and the Department of Land and Natural Resources, Division of Water and Land Development, without delay for preparation of any report.

Preparation of Formal and Periodic or Intermediate Reports

Formal and periodic or intermediate reports should be prepared for each dam investigated for submission to that party for which the report was prepared. In addition, a copy of the report should be submitted to the Department of Land and Natural Resources, Division of Water and Land Development. Each report should contain the information indicated in the following paragraphs. The signature and registration identification of the professional engineer who directed the investigation and who was responsible for evaluation of the dam should be included in the report.

Phase I Reports

Phase I reports should contain the following information:

1. Description of the dam including regional vicinity map showing location and plans, elevations and sections showing the essential project features and the size and hazard potential classifications.
2. Summary of existing engineering data, including geologic maps and information.

3. Results of the visual inspection of each project feature including photographs and drawings to minimize descriptions.

4. Evaluation of operational adequacy of the reservoir regulation plan and maintenance of the dam and operating facilities and features that pertain to the safety of the dam.

5. Description of any warning system in effect.

6. Evaluation of the hydraulic and hydrologic assumptions and structural stability.

7. An assessment of the general condition of the dam with respect to safety based upon the findings of the visual inspection and review of engineering data. Where data on the original design indicate significant departure from or non-conformance with guidelines contained herein, the engineer-in-charge of the investigation will give his opinion of the significance, with regard to safety, of such factors. Any additional studies, investigations and analyses considered essential to assessment of the safety of the dam should be listed, together with an opinion about the urgency of such additional work.

8. Indicate alternative possible remedial measures or revisions in operating and maintenance procedures which may (subject to further evaluation) correct deficiencies and hazardous conditions found during the investigation.

Phase II Reports

Phase II reports should describe the detailed investigations and should supplement Phase I reports. They should contain the following information:

1. Summary of additional engineering data obtained to determine the hydraulic and hydrologic capabilities and/or structural stability.

2. Results of all additional studies, investigations, and analyses performed.

3. Technical assessment of dam safety including deficiencies and hazardous conditions found to exist.

4. Indicate alternative possible remedial measures or revisions in maintenance and operating procedures which may (subject to further evaluation) correct deficiencies and hazardous conditions found during the investigation.

Routine or Informal Reports

Routine or informal dam safety inspection reports should include the following information:

1. Description of the dam including dam name, county located, owner, identification number, type of dam, hazard category if known, date, time, weather conditions, personnel present, pool and tailwater elevations.

2. List all field observations by feature, such as crest, upstream slope, downstream slope, drainage or seepage controls, abutments, and various parts of the outlet works.

3. A sample checklist for informal reports is presented in Appendix D.

Special and Emergency Reports

Special and emergency reports are prepared for specific items or details of a dam, and would not necessarily have a specific form to follow. Special inspection reports could follow specific items in the Phase I reports, while emergency reports need to address a specific item of concern.

REFERENCES

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U.S. Bureau of Reclamation, Dams and Public Safety, Robert B. Jansen, 1983.

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U.S. Bureau of Reclamation, Safety Evaluation of Existing Dams, U.S. Government Printing Office, Denver, 1983.

Wyoming State Engineer's Office, Guidelines for Maintenance and Inspection of Dams in Wyoming, 2nd Edition, July 1988.

APPENDIX A

ENGINEERING DATA

This appendix lists engineering data which should be collected from project records and, to the extent available, included in the Phase I investigation report. The list is intended to serve as a checklist and not to establish rigid data requirements. Such a compilation should also facilitate future inspections and investigations. Only data readily available will be included in Phase I reports, but data lacking and deemed necessary for an adequate safety evaluation should be identified.

1. General Project Data

   a. Regional Vicinity Map showing the location of the dam, the upstream drainage area and the downstream area subject to potential damage due to failure of the dam and misoperation or failure of the operating equipment.

   b. As-Built Drawings indicating plans, elevations and sections of the dam and appurtenant structures including the details of the discharge facilities such as outlet works, limited service and emergency spillways, flashboards, fuse plugs and operating equipment.

2. Hydrologic and Hydraulic Data including the following:

   a. Drainage area and basin runoff characteristics (indicating pending changes).

   b. Elevation of top of conservation pool or normal upper retention water surface elevation, as applicable (base level of any flood impoundment).

   c. Storage capacity including dead or inactive storage, corresponding to top of conservation or normal upper retention level (cumulative, excluding flood control and surcharge storage).

   d. Elevation of the top of the flood control pool.

   e. Storage capacity of flood control zone (incremental).

   f. Elevation of maximum design pool (corresponding to top of surcharge storage or spillway design flood).

   g. Storage capacity of surcharge zone (incremental, above top of flood control pool or, above normal upper retention level if flood control space not provided).

   h. Height of freeboard (distance between maximum design flood water surface and top of dam).

i. Elevation of top of dam (lowest point of embankment or non-overflow structure).

j. Elevation of crest, type, width, crest length and location of spillways (number, size and type of gates if controlled).

k. Type, location, entrance and exit inverts of outlet works and emergency drawdown facilities (number, size and shape of conduits and gates, including penstocks and sluices).

l. Location, crest elevation, description of invert and abutments (concrete, rock, grass, earth) and length of limited service and emergency spillways.

m. Location and description of flashboards and fuse plugs, including hydraulic head (pool elevation) and other conditions required for breaching, along with the assumed results of breaching.

n. Location and top elevation of dikes and floodwalls (overflow and non-overflow) affected by reservoir. Include information on low reaches of reservoir rim.

o. Type, location, observations and records of hydrometeorological gages appurtenant to the project.

p. Maximum non-damaging discharge, or negligible damage rate, at potential damage locations downstream.

3. Foundation Data and Geological Features including logs of boring, geological maps, profiles and cross sections, and reports of foundation treatment.

4. Properties of Embankments and Foundation Materials including results of laboratory tests, field permeability tests, construction control tests, and assumed design properties for materials.

5. Concrete Properties including the source and type of aggregate, cement used, mix design data and the results of testing during construction.

6. Electrical and Mechanical Equipment type and rating of normal and emergency power supplies, hoists, cranes, valves and valve operator, control and alarm systems and other electrical and mechanical equipment and systems that could affect the safe operation of the dam.

7. Construction History including diversion scheme, construction sequence, pertinent construction problems, alterations, modifications and maintenance repairs.

8. Water Control Plan including regulation plan under normal conditions and during flood events or other emergency conditions. The availability of dam tenders, means of communication between dam tenders and authority supervising water control, and method of gate operation (manual, automatic, or remote control) should be included. Flood warning systems should be described in sufficient detail to enable assessment of their reduction in the flood hazard potential.

9. Operation Record

   a. Summary of past major flood events including any experiences that presented a serious threat to the safety of the project or to human life or property. The critical project feature, date and duration of event, causative factor, peak inflow and outflow, maximum elevation of water surface, wind and wave factors if significant, issuance of alert or evacuation warnings and adequacy of project feature involved should be included in the summary of past experience of serious threat to the safety of the project.

   b. Records of performance observations including instrumentation records.

   c. List of any known deficiencies that pose a threat to the safety of the dam or to human life or property.

d. History of previous failures or deficiencies and pending remedial measures for correcting known deficiencies and the schedule for accomplishing remedial measures should be indicated.

10. Earthquake History including a summary of the seismic data of significant recorded earthquakes in the vicinity of the dam and information on major damage in the vicinity of the dam from both recorded and unrecorded earthquakes. Regional geologic maps and other documents showing fault locations should be collected.

11. Inspection History including the results of the last safety inspection, the organization that performed the inspection, the date inspection was performed and the authority for conducting the inspection.

12. Principal Design Assumptions and Analyses

a. Hydrologic and Hydraulic Determinations

1. Quantity, time and area distribution, and reference source of depth-area-duration data of spillway design storm precipitation (point precipitation if applicable).

2. Maximum design flood inflow hydrograph including loss rates (initial and average for design flood conditions) and time of runoff concentration of reservoir watershed (peak inflow only when applicable).

3. Maximum design flood outflow hydrograph (maximum outflow only when applicable).

4. Discharge-frequency relationship, preferably at dam site, including estimated frequency of spillway design flood for small dams, when appropriate.

5. Reservoir area and storage capacity versus water surface elevation (table or curves).

6. Rating curves (free flow and partial gate openings) for all discharge facilities contributing to the maximum design flood outflow hydrograph. Also, a composite-rating of all contributing facilities, if appropriate.

7. Tailwater rating curve immediately below dam site including elevation corresponding to maximum design flood discharge and approximate nondamaging channel capacity.

8. Hydrologic map of watershed above dam site including reservoir area, watercourse, elevation contours, and principal stream-flow and precipitation gaging stations.

b. Stability and Stress Analysis of the dam, spillway and appurtenant structures and features including the assumed properties of materials and all pertinent applied loads.

c. Seepage and Settlement Analyses - The determination of distribution, direction and magnitude of seepage forces and the design and construction measures for their control. Settlement estimates and steps adopted to compensate for total settlement and to minimize differential settlements.

APPENDIX B

INSPECTION ITEMS

This appendix provides guidance for performing field inspections and may serve as the basis for developing a detailed checklist for each dam.

1. Concrete Structures in General

   a. Concrete Surfaces - The condition of the concrete surfaces should be examined to evaluate the deterioration and continuing serviceability of the concrete. Descriptions of concrete conditions should conform with the appendix to "Guide for Making a Condition Survey of Concrete in Service," American Concrete Institute (ACI) Journal, Proceedings Vol. 65, No. 11, November 1968, page 905-918.

   b. Structural Cracking - Concrete structures should be examined for structural cracking resulting from overstress due to applied loads, shrinkage and temperature effects or differential movements.

   c. Movement - Horizontal and Vertical Alignment - Concrete structures should be examined for evidence of any abnormal settlements, heaving, deflections or lateral movements.

   d. Junctions - The conditions at the junctions of the structure with abutments or embankments should be determined.

   e. Drains - Foundations, Joint, Face - All drains should be examined to determine that they are capable of performing their design function.

   f. Water Passages - All water passages and other concrete surfaces subject to running water should be examined for erosion, cavitation, obstructions, leakage or significant structural cracks.

   g. Seepage or Leakage - The faces, abutments and toes of the concrete structures should be examined for evidence of seepage or abnormal leakage, and records of flow of downstream springs reviewed for variation with reservoir pool level. The sources of seepage should be determined if possible.

   h. Monolith Joints - Construction Joints - All monolith and construction joints should be examined to determine the condition of the joint and filler material, any movement of joints, or any indication of distress or leakage.

i. Foundation - Foundations should be examined for damage or possible undermining of the downstream toe.

j. Abutments - The abutments should be examined for signs of instability or excessive weathering.

2. Embankment Structures

a. Settlement - The embankments and downstream toe areas should be examined for any evidence of localized or overall settlement, depressions or sink holes.

b. Slope Stability - Embankment slopes should be examined for irregularities in alignment and variances from smooth uniform slopes, unusual changes from original crest alignment and elevation, evidence of movement at or beyond the toe, and surface cracks which indicate movement.

c. Seepage - The downstream face of abutments, embankment slopes and toes, embankment - structure contacts, and the downstream valley areas should be examined for evidence of existing or past seepage. The sources of seepage should be investigated to determine cause and potential severity to dam safety under all operating conditions. The presence of animal burrows and tree growth on slopes which might cause detrimental seepage should be examined.

d. Drainage Systems - All drainage systems should be examined to determine whether the systems can freely pass discharge and that the discharge water is not carrying embankment or foundation material. Systems used to monitor drainage should be examined to assure they are operational and functioning properly.

3. Spillway Structures - Examination should be made of the structures and features including bulkheads, flashboards, and fuse plugs of all service and auxiliary spillways which serve as principal or emergency spillways for any condition which may impose operational constraints on the functioning of the spillway.

a. Control Gates and Operating Machinery - The structural members, connections, hoists, cables and operating machinery and the adequacy of normal and emergency power supplies should be examined and tested to determine the structural integrity and verify the operational adequacy of the equipment. Where cranes are intended to be used for handling gates and bulkheads, the availability, capacity and condition of the cranes and lifting beams should be investigated. Operation of control systems and protective and alarm devices such as limit switches, sump high water alarms and drainage pumps should be investigated.

b. Unlined Saddle Spillways - Unlined saddle spillways should be examined for evidence of erosion and any conditions which may impose constraints on the functioning of the spillway. The ability of the spillway to resist erosion due to operation and the potential hazard to the safety of the dam from such operation should be determined.

c. Approach and Outlet Channels - The approach and outlet channels should be examined for any conditions which may impose constraints on the functioning of the spillway and present a potential hazard to the safety of the dam.

d. Stilling Basin (Energy Dissipators) - Stilling basins including baffles, flip buckets or other energy dissipators should be examined for any conditions which may pose constraints on the ability of the stilling basin to prevent downstream scour or erosion which may create or present a potential hazard to the safety of the dam. The existing condition of the channel downstream of the stilling basin should be determined.

4. Outlet Works - The outlet works examination should include all structures and features designed to release reservoir water below the spillway crest through or around the dam.

a. Intake Structure - The structure and all features should be examined for any conditions which may impose operational constraints on the outlet works. Entrances to intake structure should be examined for conditions such as silt or debris accumulation which may reduce the discharge capabilities of the outlet works.

b. Operating and Emergency Control Gates - The structural members, connections, guides, hoists, cables and operating machinery including the adequacy of normal and emergency power supplies should be examined and tested to determine the structural integrity and verify the operational adequacy of the operating and emergency gates, valves, bulkheads, and other equipment.

c. Conduits, Sluices, Water Passages, etc. - The interior surfaces of conduits should be examined for erosion, corrosion, cavitation, cracks, joint separation and leakage at cracks or joints.

d. Stilling Basin (Energy Dissipator) - The stilling basin or other energy dissipator should be examined for conditions which may impose any constraints on the ability of the stilling basin to prevent downstream scour or erosion which may create or present a potential hazard to the safety of the dam. The existing condition of the channel downstream of the stilling basin should be determined by soundings.

e. Approach and Outlet Channels - The approach and outlet channels should be examined for any conditions which may impose constraints on the functioning of the discharge facilities of the outlet works, or present a hazard to the safety of the dam.

f. Drawdown Facilities - Facilities provided for drawdown of the reservoir to avert impending failure of the dam or to facilitate repairs in the vent of stability or foundation problems should be examined for any conditions which may impose constraints on their functioning as planned.

5. Safety and Performance Instrumentation

a. Headwater and Tailwater Gages - The existing records of the headwater and tailwater gages should be examined to determine the relationship between other instrumentation measurements such as stream flow, uplift pressures, alignment, and drainage system discharge with the upper and lower water surface elevations.

b. Horizontal and Vertical Alignment Instrumentation (Concrete Structures) - The existing records of alignment and elevation surveys and measurements from inclinometers, inverted plumb bobs, gage points across cracks and joints, or other devices should be examined to determine any change from the original position of the structure.

c. Horizontal and Vertical Movement, Consolidation, and Pore-Water Pressure Instrumentation (Embankment Structures) - The existing records of measurements from settlement plates or gages, surface reference marks, slope indicators and other devices should be examined to determine the movement history of the embankment. Existing piezometer measurements should be examined to determine if the pore-water pressures in the embankment and foundation would, under given conditions, impair the safety of the dam.

d. Uplift Instrumentation - The existing records of uplift measurements should be examined to determine if the uplift pressures for the maximum pool would impair the safety of the dam.

e. Drainage System Instrumentation - The existing records of measurements of the drainage system flow should be examined to establish the normal relationship between pool elevations and discharge quantities and any changes that have occurred in this relationship during the history of the project.

f. Seismic Instrumentation - The existing records of seismic instrumentation should be examined to determine the seismic activity in the area and the response of the structures to past earthquakes.

6. Reservoir

a. Shore Line - The land forms around the reservoir should be examined for indications of major active or inactive landslide areas and to determine susceptibility of bedrock stratigraphy to massive landslides of sufficient magnitude to significantly reduce reservoir capacity or create waves that might overtop the dam.

b. Sedimentation - The reservoir and drainage area should be examined for excessive sedimentation or recent developments in the drainage basin which could cause a sudden increase in sediment load, thereby, reducing the reservoir capacity with attendant increase in maximum outflow and maximum pool elevation.

c. Potential Upstream Hazard Areas - The reservoir area should be examined for features subject to potential backwater flooding resulting in loss of human life or property at reservoir levels up to the maximum water storage capacity including any surcharge storage.

d. Watershed Runoff Potential - The drainage basin should be examined for any extensive alterations to the surface of the drainage basin such as changed agriculture practices, timber clearing, railroad or highway construction or real estate developments that might extensively affect the runoff characteristics. Upstream projects that could have impact on the safety of the dam should be identified.

7. Downstream Channel - The channel immediately downstream of the dam should be examined for conditions which might impose any constraints on the operation of the dam or present any hazards to the safety of the dam. Development of the potential flooded area downstream of the dam should be assessed for compatibility with the hazard classification.

8. Operation and Maintenance Features

a. Reservoir Regulation Plan - The actual practices in regulating the reservoir and discharges under normal and emergency conditions should be examined to determine if they comply with the designed reservoir regulation plan and to assure that they do not constitute a danger to the safety of the dam or to human life or property.

b. <u>Maintenance</u> - The maintenance of the operating facilities and features that pertain to the safety of the dam should be examined to determine the adequacy and quality of the maintenance procedures followed in maintaining the dam and facilities in safe operating condition.

APPENDIX C

GENERAL AND SPECIALIZED EQUIPMENT

This appendix lists general and specialized equipment normally used to conduct field inspections during safety inspection of dams. The list is intended to serve as a checklist for field personnel.

1. General Equipment

   a. Hand level - used for checking elevations and heights (approximate)

   b. Philadelphia or fiberglass surveying rod - used for checking elevations and heights

   c. Tapes (6-, 25-, 100-ft. tapes) - measuring dimensions of features or abnormalities and location relative to a known reference

   d. Inclinometer - measuring the degree of slopes

   e. Rock hammer - sounding concrete or rock to check quality and checking for pipe corrosion

   f. Shovel - Clearing drains, and exposing covered appurtenances

   g. Lights - Looking into pipes, spillways, or darkened areas

   h. Probe Rod - Probing wet, soft areas, sinkholes, and voids

   i. Bucket and timer - measuring seepage and other flow rates

   j. Bonker - sounding concrete for voids

   k. Knife or machete - scraping rock or soil and clearing brush

   l. Chain saw - cutting away thick underbrush

   m. Sounding lines or tapes - measuring water depths in standpipes and foundation drains

   n. Binoculars - Viewing inaccessible structures and areas

   o. Camera - Making photographic records

p. Water sample containers - performing water quality tests

q. Miscellaneous surveying equipment - performing various measurements

2. Specialized Equipment

a. Plumb bob - checking alignment

b. Flow meter - measuring flow velocity and quantity

c. Piezometer gauge - reading piezometers

d. Remotely operated vehicle with video camera - inspecting pipes and conduits and conducting underwater inspections.

e. Video tape camera and recorder - recording general inspection findings, discharge in the spillway, and equipment operation

f. Two way radios - communication during inspection

g. Pre-cut V-notch weirs - measuring seepage

h. Large pipe wrench - removing caps from piezometers

APPENDIX D

INSPECTION CHECKLIST FORM

NAME OF DAM: ______________________ DATE INSPECTED: ______________________

COUNTY: ______________________ INSPECTED BY: ______________________

OWNER: ______________________ WEATHER: ______________________

INVENTORY NO.: ______________________ POOL ELEVATION: ______________________

HAZARD CATEGORY: ______________________ TAILWATER ELEVATION: ______________________

DIRECTIONS: MARK AN "X" IN THE YES OR NO COLUMN. IF AN ITEM DOES NOT APPLY, WRITE "NA" IN THE REMARKS COLUMN.

ITEM	YES	NO	REMARKS
EMBANKMENT			
1. UPSTREAM SLOPE			
Any erosion or slides			
Are trees growing on slope			
Longitudinal cracks			
Transverse cracks			
Deficient riprap protection			
Any stone deterioration			
Visual depressions or bulges			
Visual settlements			
Burrows			
2. CREST			
Any visual settlements			
Misalignment			
Cracking			
Are trees growing on crest			
3. DOWNSTREAM SLOPE			
Any erosion or slides			
Are trees growing on slope			
Longitudinal cracks			
Transverse cracks			
Visual depressions or bulges			
Visual settlements			
Burrows			
Soft spots or boggy areas			
Movement at or beyond toe			

ITEM	YES	NO	REMARKS
4. DRAINAGE OR SEEPAGE CONTROL			
Internal drains flowing			
Are boils present			
Is seepage present			
Does seepage contain fines			
5. ABUTMENTS			
Any erosion			
Visual differential movement			
Any cracks noted			
Is seepage present			
Any slides, depressions, bulges			
RESERVOIR AREA			
1. Slides in reservoir area			
2. Debris producing areas in watershed			
3. Sediment producing areas in watershed			
4. Depressions, sinkholes or vortices in reservoir area			
5. Low ridges/saddles allowing overflow from reservoir			
6. Structures below elevation of maximum surcharge storage			

Additional Comments:

ITEM	YES	NO	REMARKS
SPILLWAY			
1. APPROACH CHANNEL			
Eroding or backcutting			
Sloughing			
Restricted by vegetation			
Obstructed with debris			
Silted in			
2. CONTROL STRUCTURE			
Does concrete show:			
1. Spalling			
2. Cracking			
3. Erosion			
4. Scaling			
5. Exposed reinforcement			
Do joints show:			
1. Displacement or offset			
2. Loss of joint material			
3. Leakage			
If spillway is earth cut:			
1. Are slopes eroding			
2. Are slopes sloughing			
3. Is crest eroding			
If controlled spillway			
1. Are gates bent/broken			
2. Are they corroded/rusted			
3. Are controls, hoists, etc. in need of repair			
4. Not maintained			
5. Not Operated Periodically			
6. Date last operated			
7. When closed, do they leak			
Is weir in poor condition			
Where is control structure			

ITEM	YES	NO	REMARKS
3. CONVEYANCE STRUCTURE (SPILLWAY CONT.)			
If structure is concrete			
1. Do concrete surfaces show:			
a. Spalling			
b. Cracking			
c. Erosion			
d. Scaling			
e. Exposed reinforcement			
2. Do joints show:			
a. Displacement or offset			
b. Loss of joint material			
c. Leakage			
Does concrete show:			
1. Does channel show erosion			
2. Side slopes show sloughing			
3. Is channel poorly protected with vegetation/riprap			
4. TERMINAL STRUCTURE			
Do concrete surfaces show:			
1. Spalling			
2. Cracking			
3. Erosion			
4. Scaling			
5. Exposed reinforcement			
Do joints show:			
1. Displacement			
2. Loss of joint material			
3. Leakage			
Do energy dissipators show:			
1. Signs of deterioration			
2. Are they covered w/ debris			
3. Signs of inadequacy			
5. OUTLET CHANNEL			
Is the channel:			
1. Eroding or backcutting			
2. Sloughing			
3. Obstructed			
4. Inadequately riprapped			

ITEM	YES	NO	REMARKS
OUTLET WORKS			
1. APPROACH CHANNEL			
Eroding or backcutting			
Sloughing			
Restricted by vegetation			
Obstructed with debris			
Silted in			
2. INTAKE STRUCTURE			
Do concrete surfaces show:			
1. Spalling or Scaling			
2. Cracking			
3. Erosion			
4. Exposed reinforcement			
Do joints show:			
1. Displacement or offset			
2. Loss of joint material			
3. Leakage			
Metal Appurtenances			
1. Corrosion present			
2. Breakage present			
3. Anchor system poorly secured			
Obstructed by silt & debris			
3. CONVEYANCE STRUCTURE			
If structure is concrete			
1. Do concrete surfaces show:			
a. Spalling			
b. Cracking			
c. Erosion			
d. Scaling			
e. Exposed reinforcement			
2. Do joints show:			
a. Displacement or offset			
b. Loss of joint material			
c. Leakage			
If conduit is metal			
1. Is corrosion present			
2. Protective coating deficient			
3. Is the conduit misaligned			

NAME OF DAM: ______________________

ITEM	YES	NO	REMARKS
4. CONTROL STRUCTURE (OUTLET WORKS CONT.)			
Are service gates in need of repair			
Emergency gates/stop logs in need of repair			
Are control valves in need of repair			
Are they bent/broken			
Are they corroded/rusted			
Not maintained			
Unoperational			
When closed, do they leak			
Date last operated			
Is cold water return not operational			
Is the low level outlet not operational			
5. TERMINAL STRUCTURE			
Do concrete surfaces show:			
1. Spalling			
2. Cracking			
3. Erosion			
4. Scaling			
5. Exposed reinforcement			
Do joints show:			
1. Displacement			
2. Loss of joint material			
3. Leakage			
Do the energy dissipators:			
1. Show signs of deterioration			
2. Covered with debris			
3. Show signs of inadequacy			
6. OUTLET CHANNEL			
Is the channel:			
1. Eroding or backcutting			
2. Sloughing			
3. Obstructed			
4. Poorly riprapped			

NAME OF DAM: ____________________

ITEM	YES	NO	REMARKS
DOWNSTREAM AREA			
1. Bridges or culverts that may restrict discharge			
2. Other obstructions which interfere with discharge			
3. Channel headcutting			
4. Downstream floodwalls, levies dikes			
5. Reservoir-connected "springs"			
6. Buildings in flood plain			
7. Overnight recreational sites			
8. Public access sites			
PROJECT AREA			
1. SITE ACCESS			
A. Roads to site inadequate			
B. Unreliable under all weather conditions			
C. Unreliable at all reservoir & river stages			
2. SPILLWAY AND OUTLET CONTROL ACCESS			
A. Are catwalks, ladders, bridges insecurely anchored			
B. Are they unsafe			
C. Are they below elevation of high water			
INSTRUMENTATION			
1. List type(s) of instrumentation			
2. In poor condition			
3. Not read periodically			
4. Is data unavailable			
Notes: List upstream dams			
List downstream dams			
List any high water mark			
(Elev)			