CHAPTER 14

DAM SAFETY
PERFORMANCE MONITORING PROGRAM

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14.1 INTRODUCTION

The guidelines presented in this chapter provide recommended procedures and criteria to develop a Performance Monitoring Program based upon "failure mode thinking" to assist in reviewing and evaluating the safety and performance of water retaining project works regulated by FERC. The procedure includes:

- A Potential Failure Mode Analysis (PFMA); and
- Development of a Performance Monitoring Program (PMP).

The Potential Failure Mode Analysis is conducted jointly by the licensee, Independent Consultant and FERC staff. For the most part the PFMA is a one-time exercise. Guidance on conducting a PFMA is provided in Section 14.3

Based upon the results of the PFMA, the Performance Monitoring Program is developed. The PMP defines the appropriate monitoring for the water retaining project works based upon the PFMA. An integral part of the PMP is the integration of the licensee's operation, maintenance and inspection programs.

In addition, the Part 12D Independent Consultant's inspection and report and the FERC's inspection program will also be focused using the PFMA and the PMP.

The integration of a Potential Failure Mode Analysis with a Performance Monitoring Program, results in a more efficient and effective dam safety program. With the knowledge, vision, and understanding gained from a PFMA, the PMP will be highly effective. The added value to dam safety includes:

- Uncovering data and information that corrects, clarifies, or supplements the understanding of potential failure modes and scenarios;
- Identifying the most significant potential failure modes;
- Identifying risk reduction opportunities;
- Focusing instrumentation, monitoring and inspection programs to provide information on the potential failure modes that present the greatest risk to the safety of the dam; and
- Developing operating procedures to assure that there are no weak links that could lead to mis-operation failures.

Although the traditional emphasis of Part 12D inspections has been on project dams, 18CFR12.32 specifically states that all project works with the exception of transmission and transformation facilities and generating equipment are to be included in the inspection by the independent consultant. In addition, certain other water retaining structures such as canals, flumes, tunnels and penstocks may impact public safety if they were to fail. Accordingly, these types of project works may also warrant a PFMA. In this document dam and project works may be used interchangeably to designate those licensed project works that could impact public safety in the event of a failure.

14.2 INSPECTION PROCESS and COORDINATION

14.2.1 Scope and Purpose

To define the roles, responsibilities and coordination of the Licensee, Independent Consultant and FERC and to develop a process flowchart which links together all of the inspection, analysis, evaluation and emergency action planning elements of the FERC's dam safety program using a potential failure mode analysis approach.

14.2.2 Description and Interrelationship of Dam Safety Program Elements Using a Potential Failure Mode Analysis Approach

1. Daily routine inspections / observations - Persons performing the routine inspections or observations should be provided with background information on the potential failure modes identified for the site along with a performance monitoring and visual surveillance plan for each potential failure mode. The licensee is responsible for performing these inspections and for coordinating with the FERC resolution of any issues discovered during the inspections. After a discussion with FERC, a decision will be made whether any action such as analysis, repairs or monitoring needs to be implemented.

2. Licensee operation and maintenance inspection and training programs - Those persons performing the inspections or observations should be provided with background information on the potential failure modes identified for the site along with performance monitoring and visual surveillance plan for each potential failure mode. The licensee is responsible for ensuring that its personnel are properly trained and remain current in the knowledge of proper operation and maintenance of the project. Any deficiencies in these matters need to be coordinated with FERC.

3. FERC operation inspection - FERC will schedule with the licensee in advance and perform this inspection. After the inspection FERC will discuss with Licensee any concerns found during the inspection. The discussion will also include various items relating to the project, such as the operation and maintenance of the project, any instrumentation and monitoring currently at the project and the emergency action plan that is in place at the project site.

   If during the FERC operation inspection a new potential failure mode is identified, the FERC will provide this information to the licensee in the Operation Inspection follow-up letter. If the potential failure mode needs to be evaluated prior to the next Part 12D inspection, a schedule will be established to accomplish this. If it is determined that evaluation of the potential failure mode may be delayed until the next Part 12D Inspection, the FERC will include the request in its one year reminder letter to the licensee.

   FERC will document this inspection.

4. Joint Part12D and FERC Operation Inspection - Every 5 years a joint inspection will be made by the Independent Consultant and FERC with proper coordination and support of the licensee.

   The FERC Operation Inspection will be done at the same time that the Part 12D Inspection is done.

   The Consultant will be provided the current Potential Failure Mode Analysis (initial plus any updates). The first ½ to 1 day will be devoted to a meeting between the necessary licensee representatives and the consultant to review the project history including any past or current deficiencies, completed remediation, special investigations previously completed, instrumentation, etc. The group will discuss the development of performance parameters and potential failure modes.

   The FERC's operation inspection and the consultant's Part 12D inspection, though conducted concurrently, will take place and be done independently. It is intended that the inspections allow opportunities for discussions of any problem areas and other important items that might come up.

   Upon completion of the inspections, the group will meet to discuss any additional thoughts concerning the performance parameters and the potential failure modes to be developed.

   The performance parameters and the potential failure modes will be prepared by the Independent Consultant and included as appendices to the Part 12D report.

5. FERC Construction and Special Inspections - FERC will be responsible for performing and documentation of these inspections on as needed bases with proper coordination with the Licensee.

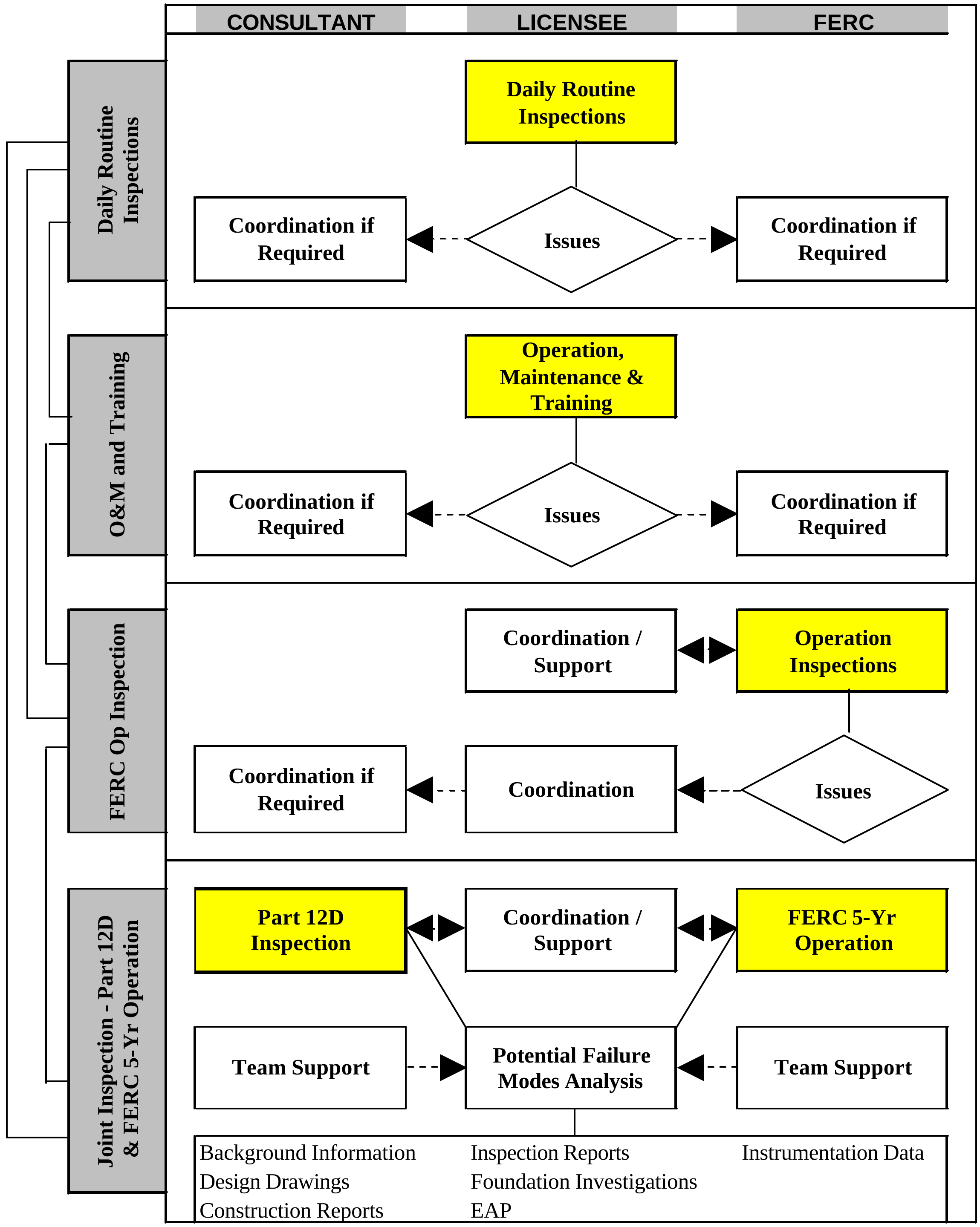
6. Licensee Initiated and FERC Directed Analyses and Evaluations - If during the operation or inspection of the project a concern or issue is raised that requires additional studies it is the responsibility of the party identifying the concern or issue to initiate a discussion with all parties involved. If policies change as to the design standards, FERC may direct further analyses and evaluation to determine if a deficiency exists.

7. Recommended Action

   Performance monitoring - If after the PFMA a concern or issue is thought to require monitoring to determine if the dam's performance is at risk, it will be the responsibility of the Licensee to install, monitor, and evaluate monitoring instrumentation with the coordination of the Consultant and FERC.

   Modification - If after the PFMA a modification is required it will be the responsibility of the Licensee to design and make the necessary modifications, with the coordination of the Consultant and FERC.

14.2.3 Process flowchart



14.3 POTENTIAL FAILURE MODE ANALYSIS

14.3.1 Introduction

Potential Failure Modes Analysis is intended to be a tool utilized in the context of the existing Part 12D program of dam and project works safety evaluation. Traditional dam and project works safety evaluations have tended to focus on a limited number of "standards based" concerns such as hydraulic capacity of spillways and stability of structures under a set of pre-defined load conditions. PFMAs are intended to broaden the scope of the safety evaluations to include potential failure scenarios that may have been overlooked in past investigations. By definition, a Potential Failure Mode Analysis is an exercise to identify all potential failure modes under static loading as well as all external loading conditions for water retaining structures and to assess those potential failure modes of enough significance to warrant continued awareness and attention to visual observation, monitoring and remediation as appropriate.

This section provides the following:

- A brief description of a Potential Failure Mode Analysis;
- A listing of the key goals and outcomes anticipated from a PFMA;
- Guidance for the conduct of a PFMA is given in two ways:
  - A brief statement of the expectations and requirements for a PFMA
  - Detailed, step by step guidance for the conduct and documentation of a PFMA modeled after a procedure that has been successfully used for conducting PFMAs on a large number of dams.

  These descriptions are intended to serve as guidance for the conduct of the "initial" Potential Failure Mode Analyses to be carried out on all FERC regulated projects subject to Part 12, Subpart D Safety Inspections
- A description of the intended application of the results of the PFMA as a support document for conducting the FERC Part 12 Dam Safety Examination with specific emphasis on the development of the Performance Monitoring Program for the project; and
- A description of the process for "updating of the PFMA" by future Part 12 independent consultants.

14.3.2 Description

A Potential Failure Mode Analysis is an informal examination of "potential" failure modes for an existing dam or other project work(s) by a team of persons who are qualified either by experience or education to evaluate a particular structure. It is based on a review of existing data and information, first hand input from field and operational personnel, site inspection, completed engineering analyses, identification of potential failure modes, failure causes and failure development and an understanding of the consequences of failure. The PFMA is intended to provide enhanced understanding and insight on the risk exposure associated with the dam. This is accomplished by including and going beyond the traditional means for assessing the safety of project works and by intentionally seeking input from the diverse team of individuals who have information on the performance and operation of the dam. A PFMA includes and uses all of the available data and information from a standard engineering analysis of an existing dam. A PFMA should be viewed as a supplement to the traditional process in which a dam's safety is judged upon its ability to pass standards-based criteria for stability and other conditions.

Utilizing an intensive team inquiry beginning from a basis of no preconceived notions, the potential failure mode examination process has the ability to:

- Enhance the dam safety inspection process by helping to focus on the most critical areas of concern unique to the dam under consideration
- Identify operational related potential failure modes and structural related potential failure modes (e.g. piping) not covered by the commonly used analytical methods (e.g. slope stability, seismic analysis)
- Enhance and focus the visual surveillance and instrumented monitoring program
- Identify shortcomings or oversights in data, information or analyses necessary to evaluate dam safety and each potential failure mode
- Help identify the most effective dam safety risk reduction measures.
- If the study is documented and used for guidance on future dam safety inspections and is updated (as a living document) then the benefit (of increased understanding and insight) lives on.

14.3.3 Key Goals and Typical Outcomes

The primary product and the main focus of a Potential Failure Mode Analysis is identifying and obtaining a clear understanding of each dam's – site specific - potential failure modes. The potential failure mode "identification" is intended to go beyond a simple generic statement of the potential problem (e.g. – operations, piping, slope instability, foundation, overtopping, liquefaction, etc.). The potential failure mode identification, examination and description provides background information on the loadings and structure conditions, circumstances and events at each site that identify why this potential failure mode is being considered for this site. Also the significance of this potential failure mode for the site in terms of the need for awareness, for monitoring and surveillance, for analyses and investigation or for making operational changes or structural repairs is discussed. Example descriptions of potential failure modes that have come from actual potential failure mode analyses are provided in Appendix A for a potential operational type potential failure mode and for a potential piping type failure.

The Potential Failure Mode Analysis (PFMA) process is not a substitute for but rather a guide to help focus periodic, comprehensive, dam safety inspections. Both activities require and benefit from a comprehensive review and discussion of **all** available information (historic records and photos, engineering analyses, previous inspection reports, etc.). Hence, the detailed reviews commonly done prior to a periodic inspection, especially if an Independent Consultant is not familiar with a project, are still necessary. Linking the accomplishments of the PFMA and periodic inspections is efficient and effective because it allows others, not often in the direct safety evaluation loop, to participate and contribute importantly to the outcome.

Every organization / dam owner / dam regulator / A-E firm currently carries out or participates in dam safety inspections for dams under their charge. It is suggested that the inspections in the future should incorporate "potential failure mode thinking", and that integration of potential failure mode analyses and dam safety inspections can be adapted to meet the needs and resources of all dam owners.

Although potential failure mode identification is the focus product from the process there are other outcomes that result from carrying out a PFMA in the manner described in this guidance document.

- The process of searching out all the information about the dam for the specific purpose of identifying potential failure modes (plus the involvement of a diverse group of people in the PFMA process), typically results in uncovering data and information that most personnel currently involved in the dam's safety evaluation had not been aware of. Frequently this information plays an important role in identifying a potential failure mode.
- The most significant potential failure modes and failure scenarios will be identified and documented for use and consideration by future Independent Consultants and inspection teams.
- Certain problems, issues and concerns that have been associated with the dam may be found to be of lesser significance than previously perceived from the standpoint of consequence, remoteness or physical possibility.
- Enhancements to the monitoring and visual inspection programs are recognized and readily developed. Monitoring efforts can become more focused on the important issues.
- A wide range of persons (from the dam tender to the owner's dam safety program manager), become aware of the dam's most significant vulnerabilities and the relationship of the surveillance and monitoring programs to these vulnerabilities.
- Gaps in data, information or analyses that prevent characterizing the significance of a potential failure mode are recognized and identified for consideration / action by the owner.
- Non-structural risk reduction opportunities applicable to the Dam Safety Performance Monitoring Program, operations, structure response or emergency preparedness are recognized and identified for consideration by the owner.
- Provides the opportunity to easily and effectively educate all who are concerned with the dam – (dam tender – owner –regulator- periodic reviewers – inspectors – designers and others) about:

    1. The potential failure modes for this dam

2. How monitoring, including use of specific instrumentation and visual surveillance is used to look for specific symptoms, behaviors or evidence that might warn of a developing failure for the identified potential failure modes and,
3. How “general health” monitoring (e.g. – crest monitoring, piezometers) is used as basic data to help watch for conditions that were not identified as potential failure modes.
4. How operations (i.e., regulated, normal, unusual) of this dam and others upstream may influence dam safety.
5. Emergency actions that may be more commonly encountered

14.3.4 Conduct of the “Initial” Potential Failure Mode Analysis

A Potential Failure Mode Analysis is to be conducted for all FERC regulated dams that are required to undergo Independent Consultant safety inspections as defined in 18 CFR Part 12, Subpart D unless granted an exemption.

Specific steps and actions for carrying out a PFMA for a dam are enumerated below and these steps are recommended, as a minimum, for a PFMA to be comprehensive, consistent, and complete. However, in completing these specific steps it is very important that the principles of the process be understood and followed in order for the full value of the process to be achieved. These principles include:

- Diligence in searching for all the background information.
- An open – investigative attitude toward identifying and understanding potential failure modes and failure scenarios.
- Dedication of the assigned persons to the reviewing / reading of all the background information on the dam prior to the PFMA session.
- Diversity in input to the process – field personnel, operations personnel, technical personnel, management personnel and others all contribute to the pool of information. There is no monopoly on good ideas and key information.
- Documentation is the key to capturing the insight and ideas resulting from the process.
- Willingness of all parties to set aside their normal hats and focus on what the data, information, and experience / knowledge of individuals can teach us about the dam.

The FERC in association with Dam Owners and the Independent Consultants who perform the Part 12 Dam Safety Evaluations have developed these procedures for use as a focal point within the Part12 Examination Process. Specifically, they combine plans to improve and focus the Dam Safety Performance Monitoring Programs for FERC regulated dams, and also provide a fundamental enhancement to the inspection process by focusing on site-specific factors of greatest importance at each project. The Potential Failure Mode Analysis, as outlined below, will serve as the focal point and linking feature within the Part 12 Inspection.

Guidance for the conduct of a PFMA is given below in two ways:

1. A statement of what needs to be done – in terms of expectations and requirements.
2. Step by step procedural guidance for carrying out a PFMA that ties directly to the statement of expectations and requirements. This is provided for those who desire more detailed guidance.

Overall Guidance – Potential Failure Mode Analysis Expectations / Requirements

1. Collect all data, studies and information on the investigation, design, construction, analysis, performance and operation of the project. All studies and investigation reports existing that relate to the ongoing safety of the dam must be included and reviewed and evaluated. A listing should be made of the data available for review and considered in the Potential Failure Mode Analysis and included in the PFMA report documentation.
2. Visit the project site with an eye out for potential failure modes, structural and geologic conditions, review operations, and interview owners/operators for their input on potential failure modes

   A core team of at least 3 persons experienced in dam safety evaluation (familiar with dam failure mechanisms) are to review all the background information for general understanding and with these specific questions in mind:

   - How could this dam fail? (Site-specific consideration of loadings, structure condition, and project operations)
   - What happens if the dam fails?
   - Are the identified potential failure modes recognized and being appropriately monitored by visual surveillance or instrumental monitoring?
   - What actions (immediate or long term) can be taken to reduce dam failure likelihood or to mitigate failure consequences? These actions could include any of the following: data collection, analysis or investigations, operational changes, communication enhancement, monitoring enhancement and structural remediation measures.
3. Brainstorm potential failure modes and failure scenarios with a team of persons most familiar with design, analysis, performance, and operation of the dam. Record the identified potential failure modes, the reasons why each potential failure mode is favorable / less likely and adverse / more likely to occur and identify any possible actions related to each that could help reduce risk (i.e. monitoring enhancement, investigation, analysis, and/or remediation).
4. Specifically identify possible performance monitoring enhancements for each potential failure mode for consideration of the owner and the Independent Consultant in the Part 12D report.
5. Document the analysis, including immediately recording the major findings and understandings from the brainstorming session.

Procedural Guidance – Potential Failure Mode Analysis Step by Step Guidance

Step 1 Designation of the Potential Failure Mode Analysis Participants

Step 2 Collection of Background Data on the Dam for Review by the Core Team

Step 3 Site visit, interviews with key owner personnel at the Project and comprehensive review of the Background Data on the Dam by the Core Team

Step 4 Conduct the PFMA Session

Step 5 Consideration of Performance Monitoring Opportunities for Identified Potential Failure Modes - (Note the Performance Monitoring Plan for Identified Potential Failure Modes is provided to the owner by the Independent Consultant in the Part 12D report)

Step 6 Documentation of the PFMA and Performance Monitoring Requirements

The following sections describe each step in detail:

Step 1 – Designation of the Potential Failure Mode Analysis Participants

The potential failure mode analysis participants (team members) consist of all those who will participate in the brainstorming session in which potential failure modes are identified, defined, discussed and categorized. Fundamentally these are persons who have experience with the design, construction, analyses, performance and operation of the dam. A dam-experienced engineering geologist should be a part of the team and should be included in the site visit. The primary advantage of having a variety of people participate in the potential failure mode identification process (<u>and it is a very significant advantage</u>) is that more ideas and more questions are put forward, more knowledge and more information is available and a greater diversity of opinion is input to the process.

Some of the team members have specific roles and responsibilities and need to have the requisite experience and capability to fulfill these roles. These roles and requirements are given below:

Team Leader - The dam owner would designate one of the participants as the team leader, responsible for coordination activities – including coordination of the collection of background information.

Core Team - At least three of the participants are designated as the "core team members. They are the designated "<u>readers of all background material</u>". The core team members are each assigned the responsibility of reviewing / reading <u>all</u> the background information collected for the dam. One of the core team members will facilitate the PFMA session and one will be responsible for documentation of the Potential Failure Mode Analysis report. The team leader is not necessarily one of the designated "readers of the material" because the coordination / logistic activities often will divert the Team Leader's attention away from the reading and study requirements. Exceptions to this general guidance may be made if there is no other practical alternative and the team leader is judged to be ideally suited for the core team (see criteria given below).

The team will generally consist of the following four persons:

- The Independent Consultant(s) who will do the current Part 12D inspection
- Representative(s) of the Owners Staff (i.e., engineer, field operations person)
- The FERC inspector for the dam
- The Facilitator designated for the Potential Failure Mode Analysis session

The following criteria should be considered when selecting the core team members:

- The core team members should have knowledge and experience related to dam safety evaluations. It is especially helpful to have persons who have interest and knowledge related to dam failures and who have an inquisitive / investigative personality (they think like coroners or detectives).
- The facilitator would, in general, be new with respect to examining the dam's operation and history. This is considered an advantageous situation with respect to providing a fresh and vigorous look at the structure.
- Dam owner representatives who have the knowledge, skill and interest and who gain the requisite experience to serve as facilitators are encouraged to do so via an exchange program with other dam owners. Dam owners facilitating the PFMA on their own structures would not in general be considered appropriate.
- The Independent Consultant may or may not be new to the facility, but like the facilitator must have extensive experience in dams and an open mind relative to identification of potential failure modes. In accordance with current regulations the Independent Consultant must still meet FERC requirements and be approved by FERC.

Facilitator Requirements - The Potential Failure Mode Analysis (PFMA) facilitator should be a civil engineer with a broad background and experience in dam safety engineering and experience in performing a PFMA similar to that described in this guidance. A basic recommended qualification for the facilitator is that the proposed facilitator for a project should have been involved in an actual PFMA of the nature described in these guidelines.

Qualifying experience is participation as a core team member of a PFMA or actually facilitating a PFMA. This ensures that the person leading the PFMA process knows not only how the process is carried out, but also is aware of what can be accomplished. This is especially critical if the other core team members have not been through a PFMA which may often be the case. As an alternative to actual experience participating or facilitating a PFMA, the proposed facilitator should have attended an FERC sponsored Dam Safety Performance Monitoring Program Training Workshop. FERC will periodically provide training opportunities to help develop facilitators, especially during the implementation phase of this new program.

It is important to understand that if the facilitator does not accomplish the goals of the PFMA, which is identifying and obtaining a clear understanding of each dams site's specific potential failure modes, the PFMA may be required to be supplemented or redone entirely.

The facilitator is to serve as the peer reviewer of the PFMA report/documentation of findings prepared by the Independent Consultant / documentation of findings. The facilitator is to complete the Peer Review of the Major Findings and Understandings within a 5 day period and the PFMA report within a 10 day period after the Independent Consultant submits them to him.

Supplemental Resources - In addition to the team participants there are other people who have specific technical knowledge or experience that may be useful to the team. These people would be notified and asked to be available on call on the day of the PFMA session. This would include such persons as seismo-tectonic specialists, hydrologists, structural engineers, electrical engineers, mechanical engineers, geotechnical engineers, field personnel, inspectors, instrumentation personnel, emergency preparedness personnel, etc.

In formulating the team it is important to include those individuals with intimate knowledge of the project operations and structures, especially the senior dam tenders and those responsible for collecting monitoring data. The benefits from conducting this exercise include not only bringing focus to the most likely modes of failure based on engineering judgment but also through increasing the general awareness of dam safety issues by sharing knowledge at all levels. Experience has shown that it is very helpful and valuable to include senior (experienced) field personnel in the actual PFMA session because all information has not been written down and in certain cases assumptions in written reports differ from what is actually done in practice.

Step 2 - Collection and Review of the Background Data on the Dam

1. Preparation / Input by the Dam Owner's Team Leader and FERC

   The Team Leader, working in conjunction with the FERC inspector, would collect and gather for review, all background information on the project (investigation and design reports, boring logs, core reports, construction photos, inspection reports, instrumentation and surveillance data, incident reports, repair plans and specifications, etc). This data and information would be collected in a centralized location for reading by the core team members and would also need to be available during the PFMA Session. The types of material which should be collected (if available) include:

   - Any FERC or state agency construction inspection reports (these have been found to be extremely useful)
   - Current or most recent dam safety engineering analyses, including stability and stress analyses

- The most recent monitoring and instrumentation data along with the historic records of monitoring data.
- Current flood routings and any hazard / consequence analysis
- The current Emergency Action Plan
- The most up-to-date aerial photographs of the downstream areas that could potentially be impacted by failure of the project structures.
- The most recent surveys for each of the project structures (i.e. horizontal and vertical survey data). This should preferably be the survey that was conducted as part of the current Part 12D inspection.
- The most recent underwater inspection report. This should preferably be the underwater inspection that was conducted as part of the current Part 12D inspection.
- Recent meteorological and pertinent river gage records (http://waterdata.usgs.gov/nwis).
- The most recent seismic loading parameters that have been prepared for the site and print records of recent seismic activity (http://neic.usgs.gov/).

(Note: Basic demographic, seismic, meteorological and/or stream flow data should be reviewed to ensure that previous findings or assumptions related to potential failure mode hazards or consequences are up to date. Hence, recent data and information should be brought to the session or generated at the session as necessary. This will ensure that the PFMA report is an accurate representation of the likely potential failure modes and consequences based on the best information that was available on the date the exercise was conducted.)

A listing of the data available for review and considered in the Potential Failure Mode Analysis should be included in the PFMA report documentation.

An advance review package on the dam would be prepared for all participants – this package would consist of material already prepared that provides an overview of the dam and its performance. The purpose of an advance package is twofold: to give the facilitator familiarity with the dam prior to the site review and to refresh knowledge of the dam and stimulate "potential failure mode thinking" by all participants prior to the PFMA session. The previous Part 12 D Inspection report is a good "advance package document" to provide to the facilitator and the core team (and any other proposed participants) for familiarization with the project prior to the site review.

The owner should establish a means to retain / archive all the information collected for the PFMA

2. Core team members are to review all of the above information searching for site specific conditions or situations that would lead to uncontrolled release of the reservoir or other incidents, conditions or situations that would have an adverse impact. This review of materials is scheduled to occur following the site visit and discussion with project personnel.

3. A questionnaire on potential failure mode identification and performance monitoring is to be sent by the Team Leader to all PFMA participants and support personnel (Appendix B provides an example questionnaire along with a draft note to be sent explaining the request for information). Note that prior to the PFMA session, team participants, other than the core team members, are only required to complete this questionnaire, review their own files (re-acquaint themselves relative to the work within their area of expertise), and bring their historic knowledge of the project to the session. Only the core team members are responsible for reading all the historical and technical documents related to the project.

Step 3 - Site Review of the Dam and Project

1. The detailed Part 12 Inspection of the project will be performed and the accompanying report prepared by the Independent Consultant following the Potential Failure Mode Analysis. However prior to the initial PFMA session, a review of the site, "thinking" potential failure modes, is carried out with the owners personnel and includes the facilitator, the independent consultant, the FERC representative, the owner's core team representative, (these 4 comprise the core team), and an appropriate geologist for the project. Owner's may find it valuable to include all or most of the employees that they plan to have participate in the PFMA also participate in the site review session.
2. The advance review package should be sent to site review participants prior to their travel to the site. Typically the site review performed in association with the Potential Failure Mode Analysis should be scheduled just prior to the PFMA just before the core team members review the background materials. Such a schedule takes greatest advantage of the interaction between potential failure mode analysis and site visitation.
3. The site review should include the opportunity to visit with field maintenance personnel and plant operators, including but not limited to those who will be team participants.
4. The comprehensive review of background data and information on the dam by the core team is scheduled to occur following the above site visit and discussion with project personnel.

Step 4 - Conduct of the Potential Failure Mode Analysis Session

A brief description of the Potential Failure Mode Analysis Session is given below – a more comprehensive example of a typical session is given in Appendix C. It is important for the facilitator to involve all participants in the discussions and give everyone an opportunity to provide their knowledge, understanding and views on the potential failure modes, consequences and possible risk reduction actions / measures.

1. Consider the possibilities for failure, loading by loading condition (static reservoir, hydrologic, seismic, ice, debris impact and any other loading relevant to the site) for each component of the project (main dam, spillway, gates, dikes, outlet works, power plant, etc.). Consider how an uncontrolled release of the reservoir or a dam breach

could occur. Also consider total system operation aspects (communication and response [i.e., personnel, remote telemetry], facility access, weather conditions, equipment) with respect to the possibility of their contribution to development of a potential failure mode/failure scenario.

2. Team participants are asked to identify "candidate" potential failure modes. A candidate potential failure mode is discussed until a clear characterization of a potential failure mode and failure scenario is developed. However, sometimes the initial suggestion may lead to two or more separate or related potential failure modes, which need to be developed separately. Or sometimes the idea brought up as a 'candidate" and discussed is not developed as potential failure mode. Such ideas are termed "other considerations" and should be noted and documented as part of the PFMA. (see Appendix D and the documentation section below)

3. Once a candidate potential failure mode has been characterized / described such that there is a common understanding of the potential failure mode, (See Appendix A – Part 1 for example potential failure mode descriptions.) The potential failure mode description is noted on a flip chart by the facilitator and should be recorded in detail by the Independent consultant at that time; then the potential failure mode and failure sequence is discussed. The nature of the breach (or other failure condition) is defined and the potential consequences of failure are discussed. All the data, information, factors and conditions that suggest the ways that the potential failure mode is more likely or less likely to occur (adverse factors and positive factors) are noted down. (See appendix A – part 2 for an example) Also during this discussion possible actions to be taken may be suggested:

   - opportunities for risk reduction,
   - possible investigations or analyses,
   - means for monitoring/inspecting for the development of potential failure modes

   All of this information is noted (in brief) on a flip chart to facilitate documenting the suggestions.

   The consequences of failure and the circumstances surrounding a failure (advance warning, detection possibilities, impact of the failure, etc.) should be discussed for each potential failure mode during the discussion of the potential failure mode since these factors play a role in assessing how significant the potential failure mode is. However, experience has shown that it is necessary, valuable and instructive to specifically raise the topic of "consequences" as part of the PFMA and brainstorm site-specific factors and potential failure mode consequence related factors (in the event they have been overlooked during the technical discussion of the potential failure mode)

4. Occasionally a candidate potential failure mode is dismissed as a significant potential failure mode without carrying out number 3 and 4 above. In such cases the PFMA report will include its introduction under the heading of "other considerations" and identify why the team did not discuss it in further detail.

5. When each site-specific potential failure mode is identified, the nature of the breach / uncontrolled release that may occur is discussed and the range of failure scenarios and consequences that may result are identified. The emergency action plan response to potential failure scenarios is examined and any concerns with the plan are identified.

6. After a potential failure mode has been identified, described and discussed, each potential failure mode is classified / categorized according to the classification system given in Table 1 below or according to a comparable system developed to meet FERC / dam owner needs. After all potential failure modes have been discussed the classifications made are reviewed and discussed.

   The Potential Failure Mode Analysis process incorporates a qualitative likelihood estimate for the identified potential failure modes through the process of putting the potential failure modes into categories. Category I Potential Failure Modes are those considered most credible and most important to be brought to the attention of the dam owner, dam operators, personnel performing the monitoring and personnel performing routine and periodic inspections. Category II Potential Failure Modes are also considered credible, in that they are physically possible, but are not highlighted for one or more reasons such as – no direct or indirect evidence of any indication of problem development, extremely remote loading required to initiate the potential adverse response, etc. Category III Potential Failure Modes are those where more information or analyses are needed in order to be classified. Category IV PFMs are those that have been ruled out. Attention to monitoring and surveillance relates to Category II and III potential failure modes just as it does for Category I modes. (When the additional information/analyses required to resolve a Category III PFMA are completed, that potential failure mode should be categorized.) Two categories of viable potential failure modes are provided to allow the use of judgment by the team and to provide an easy differentiation of relative importance for the owner. The Categories are described as in Table 1.

7. At the close of the session, each participant takes a few minutes to note what information or understanding was most significant to them. The facilitator then records these major findings and understandings achieved as a result of the Potential Failure Mode Analysis on the flip chart.

Table 1 - Categories of Identified Potential Failure Modes

Category I - *<u>Highlighted Potential Failure Modes</u> - Those potential failure modes of greatest significance considering need for awareness, potential for occurrence, magnitude of consequence and likelihood of adverse response (physical possibility is evident, fundamental flaw or weakness is identified and conditions and events leading to failure seemed reasonable and credible) are highlighted.*

Category II - *<u>Potential Failure Modes Considered but not Highlighted</u> - These are judged to be of lesser significance and likelihood.* Note that even though these potential failure modes are considered less significant than Category I they are all also described and included with reasons for and against the occurrence of the potential failure mode. The reason for the lesser significance is noted and summarized in the documentation report or notes.

Category III - *<u>More Information or Analyses are Needed in order to Classify</u> These potential failure modes to some degree lacked information to allow a confident judgment of significance and thus a dam safety investigative action or analyses can be recommended. Because action is required before resolution the need for this action may also be highlighted.*

Category IV - *<u>Potential Failure Mode Ruled Out</u> Potential failure modes may be ruled out because the physical possibility does not exist, information came to light which eliminated the concern that had generated the development of the potential failure mode, or the potential failure mode is clearly so remote as to be non-credible or not reasonable to postulate.*

It is important to note that the Potential Failure Modes are placed into categories by judgment. The basic purpose is to help the dam owner's personnel and the current and future inspectors dealing with the dam to understand what the evaluation team considered were the most significant potential failure modes, so that they can consider / prioritize for action a smaller number of items rather than the total array of potential failure modes considered. The breakdown may also help with prioritization of actions to be taken. It is quite common in the PFMA for a monitoring or visual inspection action to be identified, often that is easy to implement, to be made for a Category II potential failure mode that is "considered but not highlighted".

Step 5 – Evaluation of Performance Monitoring Requirements

As a part of the Part 12D report the Independent Consultant will be required to present a Dam Safety Performance Monitoring Program for the dam / project. The Dam Safety Performance Monitoring Program will include a "Dam Safety Performance Monitoring Plan" for each Category I Potential Failure Mode. Dam Safety Performance Monitoring Plans will also be included for selected Category II and III Potential Failure Modes which the Independent Consultant believes are warranted. In the Part 12D report the Independent Consultant must explain why Performance Monitoring is not warranted for any specific Category II or III potential failure modes. In addition any requirements for "General Health Monitoring" independent of an identified potential failure mode will be defined. The plan presented should consider the items enumerated below. To facilitate development of Dam Safety Performance Monitoring Plans the Potential Failure Mode Analysis Team should include comment and discussion on these items as appropriate for each potential failure mode identified.

1. The type and frequency of inspections (visual surveillance requirements) should be evaluated to address the identified potential failure modes. This item may include the recommendation of developing customized checklists for the dam. (*The nature and content of the checklist, if recommended, is developed by the Independent Consultant in consultation with the owner. The checklist should identify specific visual cues that may indicate a suspected potential failure mode has activated, and the checklist should provide instructions as to what step(s) should be taken once a cue is observed).*
2. The current instrumentation and visual surveillance program should be critiqued. In some cases, instruments may be obsolete and serve no purpose in monitoring for the development of a potential failure mode. In other cases additional instrumentation or visual surveillance may be needed to monitor for a potential failure mode development
3. Reporting requirements should be reviewed. Action limits may need to be established for some of the instruments and procedures developed for reporting variations in instrumentation readings. As a minimum, annual engineering review, evaluation and reporting of the instrumentation data is required.
4. In some cases additional analyses or investigations may be required to fully evaluate a potential failure mode prior to establishing a performance monitoring plan for it. The PFMA team should identify what information is needed. The Part 12D Independent Consultant would recommend what and how to obtain this information.
5. If enhancements to the monitoring or visual surveillance are identified by the PFMA/Part 12D process then priorities for improvement in the Dam Safety Performance Monitoring Program should be discussed within the Dam Safety Performance Monitoring Program presentation and appropriate recommendations and schedules provided in the Recommendations Section of the Part 12 D Report.

Step 6 - Documentation of the Potential Failure Mode Analysis

1. For the knowledge gained, information obtained and results achieved in the Potential Failure Mode Analysis to be effectively used for the current Part 12 D and for future dam safety the Part12D inspections the documentation of the work must:

   - be done promptly
   - be definitive in describing the identified potential failure modes
   - be complete in recording factors considered relative to the viability of each potential failure mode considered
   - discuss possible risk reduction actions identified relative to each credible potential failure mode– performance monitoring – investigations – remediation activities
   - clearly relay the major findings and understandings achieved as a result of the process

   It was specifically noted during the review of pilot study draft reports that greater attention needs to be paid to fully stating the sequence of conditions and events that constitute the potential failure mode and failure scenario. (See Appendix A for an example potential failure mode description)

2. The Independent Consultant writes up the "major findings and understandings" immediately after the session. (Within 15 days of the PFMA session.) The items noted during the session are typically abbreviated and the major findings and understandings should flesh out the implication of the finding or understanding relative to the associated potential failure mode. The write up of the major findings and understandings is then sent to the facilitator for peer review and to the other core team members for input. (The facilitator peer review and input from the core team should be completed within 5 days of receipt of the write up from the independent consultant). Appendix E provides an example of a write up of major findings and understandings resulting from a potential failure mode analysis.

3. The Independent Consultant prepares the draft Potential Failure Mode Analysis Report (within 30 days of the PFMA) , describing each potential failure mode considered and referencing key adverse/likely and positive/not likely factors, identifying any suggested visual surveillance or instrumental monitoring, describing consequences of potential failure and site-specific conditions or factors related to consequences and noting any potential actions identified (information inquiries, investigations, analyses or risk reduction opportunities). The write up should include a brief statement as to the adequacy of the project documentation and overall quality of the data that formed the basis of the PFMA. If prepared technical presentations of new material, not contained in the record documents, were made by consultants during the course of the PFMA their presentation should be documented in, or appended to the PFMA report. Appendix D provides an example outline for the documentation of the analysis. This outline is designed to take advantage of the information collected on flip charts during the potential failure mode analysis session in order to make the documentation process simple, fast and effective. The facilitator

peer reviews the draft report on behalf of the Owner/Independent Consultant (within 10 days). The peer reviewed draft report is then sent by the Independent Consultant to each participant of the PFMA session for review and comment.

4. All reference material available and used by the team in the Potential Failure Mode Analysis is recorded and key items of data and information (that led to important findings or conclusions – see discussion under point 5 below) are included in an appendix to the PFMA report for ready reference. Photos of past conditions or photos of current conditions, elucidating key information about a potential failure mode, are highly recommended for inclusion in the body or appendix of the PFMA report. The PFMA appendix should be concise and not duplicate parts of the STI or Part 12D report.

5. Preparation of a listing of the documents gathered by the owner for review, in advance of the review, has been found to serve as a valuable tool for the reviewers to use during their review to assure that they have seen all the materials collected and should be included in the PFMA report.

6. The PFMA report will then become Section 1 in the Supporting Technical Information (STI) document and the findings of the PFMA report will be discussed and summarized in the Part 12 D report. It is not the intent of the PFMA appendix to include the reports and documents that comprise the "background material" that was read and used in the discussions. However, often a key paragraph, photograph, test results or other documentation is found in a document that elucidates whether or not a potential failure mode is more or less likely and it is valuable to include that specific information in the PFMA appendix. (e.g. photographs may show planar joints, or gunite treatment of the foundation, or shear keys; statements might be made by the consulting review board about the condition of the filter material, tests results might provide definitive information that counters what has been stated in opinions / observations in construction reports; erosion or the lack of it may have been documented following a flood). These specific pages, photos, quotations or data that provide direct support to the "likely" or "not likely" aspects of a potential failure mode should be reproduced and included in the appendix to the PFMA report.

7. The report should state whether the findings are a consensus of the team. If not a consensus, the reasons for differences of opinion should be documented in the report findings.

8. Other Considerations – thoughts / ideas / concepts / future changes that were considered related to possible potential failure modes that were brought up and discussed but not developed by the PFMA team as a potential failure mode should be documented in the section "Other Considerations" such that future teams will know what items were considered and why they were not carried forward as a potential failure mode at that time.

9. The report should include an assessment of the overall adequacy, completeness and relevance of background data that was furnished for the Potential Failure Mode Analysis, identify any discrepancies, inaccuracies, or deficiencies in the records, and determine if adequate information was provided to conduct the PFMA. The report

should document any potential shortcomings in the PFMA due to lack of sufficient data for consideration of specific potential failure modes.

Appendix G provides the PFMA process in a task by task table format for dam owners as a supplement to the above discussion format for their convenience if desired.

14.3.5 Use of the Potential Failure Mode Analysis report as a support document to the conduct of the FERC Part 12 Dam Safety Inspection

Appropriate sections of the Part 12D inspection and report should provide commentary and/or information that relates to and addresses the potential failure modes identified in the PFMA.

The manner in which that is intended to be accomplished is outlined in general terms below:

1. General Observations – The Part 12, Subpart D Independent Consultant should make observations of project features independent of the PFMA. It is important that the consultant keeps an open mind during the Part 12D Dam Safety inspection and be alert for any unusual conditions that may not have been identified in the PFMA. The purpose of the Part 12D inspection is not to only inspect for those conditions that may develop as described in the PFMA but to document the actual condition of the project structures. However, in addition to making these necessary observations, the consultant will also now need to pay special attention to those issues that were identified in the PFMA.
2. Inspection - The inspection report would include a discussion of the observations relative to each of the identified potential failure modes as well as the Independent Consultant's own assessment on the significance of the identified potential failure modes and on whether any other potential failure modes exist, or conditions may have changed that would impact previous conclusions regarding potential failure modes
3. Historic and current performance indicators - Any relevant comments relating these factors to identified potential failure modes are provided.
4. Performance Monitoring - Each potential failure mode identified shall be reviewed to determine whether visual surveillance or instrument monitoring is adequate to detect the onset of the potential failure mode or the onset of conditions which may contribute to or "allow" development of the potential failure mode
5. Recommendations – Actions that could be taken with regard to information inquiry, investigations, analyses, or structural or non-structural actions shall be discussed in terms of the identified potential failure modes. Recommendations may pertain to changes in operations or maintenance required in order to maintain the status quo.
6. Emergency Preparedness – discussion related to identified Potential Failure Modes
7. Independent Consultant's Commentary on the Potential Failure Modes Identified in the Potential Failure Mode Analysis - This section of the Part 12D report is provided to allow the Independent Consultant the discretion to place emphasis on or to de-emphasize any of the "team findings" presented in the Potential Failure Mode Analysis report. It also allows for incorporation of any new information, results of

analyses, or other findings that come to light during the Independent Consultant's inspection and report.

14.3.6 Updating the Potential Failure Mode Analysis

The comprehensive "initial" Potential Failure Mode Analysis and the resulting section in the STI appended to the Part12D report described above is intended to be performed only once for each project (or at extended intervals (e.g. - 15-20 years), but it should be regarded as a living document to be appended as conditions at the site change or as new information is obtained at any time following the initial PFMA or discovered during subsequent Part 12, Subpart D inspections.

If the initial Potential Failure Modes Analysis is successfully performed, then that report will serve as a key document and foundation for the Independent Consultant Inspection in subsequent Part 12 inspections. (Availability of this document should make the Independent Consultant's work easier, more focused and effective and less costly) If as a result of the detailed inspection, the Independent Consultant finds new or varying information or has a professional opinion that necessitates revision of the findings of the original PFMA, the Independent Consultant would append such revisions to the existing report, and the appended / updated PFMA document would be incorporated in the STI which accompanies each Part 12D inspection report. That "updated" PFMA would then again be the foundation for next Part 12D Independent Consultant inspection report 5 years later.

It is also possible that new information would come to light in the interim between the Part 12 inspections – the owner and FERC would append that information to the original PFMA Report in a similar fashion. In this way, the Potential Failure Mode Analysis report as maintained in Section 1 of the STI is a living document that will document the progression and variety of analyses and professional opinions that went into the current updated / appended PFMA report findings.

It is important to retain the original PFMA report as prepared so that the findings and discussions so that the thought processes at that time are retained for future evaluations.

14.4 PERFORMANCE MONITORING PROGRAM

Monitoring the performance of the dam / project to assure that possible dam failures are avoided or adequate warning time is provided is an essential part of a dam safety program. The procedures outlined in Section 14.3, above, provide guidance on developing a Potential Failure Modes Analysis for a dam.

These guidelines:

- Provide a discussion of the various performance monitoring principles and methods used to aid in evaluation of a structure; and
- Present performance monitoring procedures and principles for a number of common adverse responses or conditions that typically are indicators or contributors to potential failure modes. These basic principals and procedures provide general guidance that is then made specific for an individual dam for the potential failure modes identified as part of the PFMA process.

As part of the Part 12D report the Independent Consultant shall assess the PMP for the dam / project. The PMP will include a “Performance Monitoring Plan” for each Category I Potential Failure Mode. Performance Monitoring Plans will also be included for each selected Category II Potential Failure Mode that the Independent Consultant believes is warranted. In addition, any requirements for “General Health Monitoring” independent of an identified potential failure mode should be identified. Chapter 9 of the Engineering Guidelines provides guidance on the level of instrumentation necessary for monitoring the general health of a dam.

The adverse responses and conditions and the companion monitoring procedures and principles described in this guideline should not be considered as complete, as each dam will have its own characteristics. ALL combinations of failure, and particularly operating conditions that may present more complex potential failure modes and failure scenarios, must be developed and the appropriate means for monitoring these unique or complex modes established.

14.4.1 Principles and Methods of Performance Monitoring

This section describes fundamental principles and methods used to aid in the evaluation of the performance of a dam. Performance is assessed through evaluation of the visual observations and instrument data relative to design response expectations and subsequent observations of structural behavior.

1. **Visual observation**

   Visual observation is an important surveillance activity. Many dams were constructed without the benefit of instrumentation and thus visual observation offers a first impression to evaluating integrity, movement and loads. Visual observation at regular intervals by trained personnel will often detect unusual conditions, such as increased seepage, or cloudy seepage, or movements and is the dam owner’s primary defense against serious problems However, visual observations are judgmental rather than quantifiable. Instrumentation may be needed to provide information to enhance our ability to analyze the condition of the structures.

2. Instrumentation systems

The types of instruments used for investigating a certain behavior are generally outlined in Chapter 9. Each instrument should be reviewed for its location/depth, suitability to provide the desired information and confidence that the instrument is providing valid readings. The overall number and types of instrumentation should be reviewed to determine if they are sufficient to assess the total structure. The critical sections of the structure should be defined and the location of instruments relative to the critical section reviewed. The frequency/regularity of reading and timing of readings should be reviewed. The occurrence of taking the reading should be logically related to the date and the corresponding reservoir levels.

The personnel taking the readings should be queried for the procedures used to acquire the readings and their awareness of certain threshold levels. The procedure for processing the raw data should be reviewed for correctness and timeliness. If data are not being processed and evaluated in a timely and correct manner, personnel involved in the instrumentation and monitoring program should be reminded, and further trained if necessary, in the importance of each phase of the program and the potential impacts with respect to dam safety. The type of presentation graphs should be reviewed for the data included and the use of proper scales and format for the ability to interpret data (refer to Chapter 9 of the Engineering Guidelines). Often great clutter is apparent because graphs are presented monochromatically using only minute symbols to differentiate the lines. Project plan drawings should be prepared that clearly show the locations of all instruments at the development site should. Details of the instrument installation should also be available.

3. Comparison of instrument readings to predicted and required action levels

Threshold limits should be developed and the criteria used to develop them should be documented. Then threshold limits should be established based on the specific circumstances. In some cases, they can be based on theoretical or analytical studies (e.g. uplift pressure readings above which stability guidelines are no longer met). In other cases, they may need to be developed based on measured behavior (e.g. seepage from an embankment dam). Sometimes they may be used to identify unusual readings, readings outside the limits of the instruments, or readings which, in the judgment of the responsible engineer, demand evaluation. Both magnitude and rate of change limits may need to be established. If trends or inter-relationships between data are not clear, it may be appropriate to take more frequent measurements or collect additional complementary data

All data should be compared with design assumptions. For example, measured pore pressures and uplift pressures should be compared against those used in stability analyses. If data are available for unusual load cases, such as rapid drawdown and floods, it should be compared with assumed pressures.

More than one phreatic surface may exist where there are impervious strata in the foundation. Piezometric data should be evaluated with geologic data to identify multiple phreatic surfaces. If the phreatic surface for any strata is above the ground surface, the stability of the dam should be evaluated using the elevated phreatic surface.

All data will follow trends, such as decreasing with time or depth, increasing with time or depth, seasonal fluctuation, direct variation with reservoir or tailwater level, direct variation with temperature, or a combination of such trends. The trends are usually evident in the plotted data. Statistical analysis of data may be useful in evaluating trends that are obscured by scatter. However, such analyses are no substitute for judgment based on experience and common sense. Data inconsistent with established trends should be investigated. Readings deviating from established trends should be verified by more frequent readings. Erroneous readings should be so noted on the original data sheets and should be removed from summary tables and plots.

If no unusual behavior or evidence of problems is detected, the data should be filed for future reference. If data deviates from expected behavior or design assumptions, action should be taken. The action to be taken depends on the nature of the problem, and should be determined on a case-by-case basis. Possible actions include:

- performing detailed visual inspection;
- repeating measurements to confirm behavior;
- verify that instruments and reading devices are working properly;
- reevaluating stability using new data;
- changing frequency of measurements;
- installing additional instrumentation;
- designing and constructing remedial measures;
- operating the reservoir at a lower level; and
- emergency lowering of the reservoir.

Guidance on methods for establishing threshold parameters is presented for the various types of instrumentation described. Threshold parameters are defined as the measurement parameters that trigger need for further investigation, deliberate action or emergency action. The Independent Consultant in consultation with the licensee should establish threshold parameters.

4. Consider a way to flag instruments that are trending in an adverse manner and what additional focus should be placed on those instruments

Instruments that do not appear to be functioning properly should be further investigated. For example, data should be checked against redundant data to determine whether or not trends and magnitudes are the same. Calibration of the instruments should be checked (this is paramount). Often, tests can be devised to evaluate proper functioning.

5. Additions/deletions/duration (how long an instrument should be read)

Instrumentation, in addition to the minimum recommended, should be required wherever there is a concern regarding a condition that may affect dam safety or other critical water retaining structures. Typical reasons to require additional instrumentation are: to check design assumptions; to provide data to evaluate specific problems such as continuing movement, excessive cracking, or increased seepage; to provide data to support design of remedial modifications; and to provide data to evaluate effectiveness of remedial work. Note that continually progressive conditions may require immediate action rather than belated installation of extra instruments.

Instruments should be reviewed for their life expectancy. Readings from advanced age instruments should also be evaluated with respect to whether the instrument readings can be trusted. A failed instrument should be removed to avoid obtaining erroneous data later.

6. Redundancy

There is no such thing as a redundant instrument. All instruments should have real value, if not they should be eliminated. The only redundancy would be to use different instruments to measure the same feature.

7. Summary

Instrumentation and visual surveillance provide the means for helping to develop the understanding or verify the performance of a dam.

The purpose of instrumentation and monitoring is to help evaluate whether the dam is performing as expected and to provide a warning of developing or changing conditions that could endanger the safety of the dam. This information and data are used to maintain and improve dam safety.

If there is a discrepancy between the measured and expected behavior of the dam, it may indicate that the dam is not performing satisfactorily and that failure is developing or occurring or it may be that the data or observations do not adequately represent the behavior of the dam, or that conditions exist that were not accounted for in the expected behavior. In either case it is often useful to perform field investigations and install additional instrumentation to evaluate the behavior. Note again that rational judgment must be used to take action rather than do further investigation. If what is going on is serious enough you could put in more instruments just to see the dam fail.

14.4.2 Performance Monitoring Procedures and Guidelines

From these guidelines, necessary performance monitoring techniques and devices and threshold parameters to be employed at a specific dam can be developed. The existing performance monitoring systems in place at that specific dam can then be reviewed by the licensee, the Independent Consultant and the FERC Inspector together and supplemental performance monitoring systems agreed upon as appropriate. Additional information on the details of performance monitoring instrumentation is presented in Chapter IX, Instrumentation, of the Engineering Guidelines.

This section has been designed to acquaint you with some of the adverse responses of dams and the associated performance monitoring systems and suggested method to develop threshold parameters. Many dams will share the commonality of a potential failure mode but the PFMA must be customized for each structure. Some of the types of dams are:

- Concrete Arch Dams (including multiple arches)
- Concrete Gravity Dams (including cyclopean and RCC)
- Masonry Dams
- Earthfill Dams (homogenous dams, zoned dams, asphalt core or faced dams, and concrete or membrane faced dams.)
- Rockfill Dams (earth core dams, asphalt core or faced dams, and concrete or membrane faced dams.)
- Concrete Slab and Buttress Dams
- Timber Crib Dams
- Rubber Dams

Some typical adverse responses and conditions related to potential failure modes and scenarios are:

- Abutment or Foundation Movement
- Abutment and Foundation Seepage
- Structure Movements and Stresses
- Overtopping Washout of Abutments or Foundations
- Deterioration of Concrete
- Operations Procedures

1. Performance Monitoring Guidelines for Abutment or Foundation Movement

a. Visual Observation

The first line of defense for monitoring almost all potential failure modes is visual observation. While visual observation of gross movement of a dam or foundation would indicate that a very serious condition is occurring or developing, more subtle indications of movement can be observed. Cracking, new areas of leakage through the dam or foundation, and displaced foundation material, are all visual clues of possible movement. Visual observation is beneficial in that it may readily identify changed conditions and it has the advantage of complete coverage (as opposed to instruments that often only monitor point locations. For concrete dams pins can be established at the crest or in galleries along contraction joints to determine whether differential movement is indicated or has taken place. These pins can readily be observed during routine site visitations and after significant loading events as well as during regular inspections rather than depending only on annual surveys for an indication of movement.

b. Precise Movement Surveys – Horizontal and Vertical

Precision surveys of permanent monuments on the dam and adjacent foundation is a periodic monitoring requirement. Typically, movement monuments are placed at several points along the crest of the dam where they are line-of-site visible from benchmarks established some distance away from the dam abutments. Monuments may need to be located at foundation contact locations where abutment instability is a potential failure mode. Annual measurements of the location of such monuments provide data for detecting movements of the dam or adjacent foundation. To avoid seasonal influences on the readings, it is helpful to take the readings at the same time of each year.

c. Movement Monitoring Devices (Inclinometers, Deformeters, Tiltmeters, extensometers, optical surveys)

Devices for more frequent monitoring of small movements of structures and foundations include inclinometers (generally used to define planes of movement in soil), extensometers (measure change in distance between two fixed points), tiltmeters (measures vertical or horizontal offsets) and embedded cross-arm settlement devices for internal embankment movement. These devices are used to take frequent readings, generally quarterly, monthly or weekly, to obtain information on specific small movements, generally related to ongoing investigations or to establish movement history with regard to changing reservoir or foundation water levels or in regard to special concerns triggered by other observations.

d. Establishing Threshold Parameters for Movements

Once a series of movements over some period of time has been developed, and confirmed by stress analysis as being appropriate, threshold parameters can be established that would require further investigation or action. Before initiating action however, measurements falling outside of a threshold parameter should be carefully checked and confirmed.

Other threshold parameters can be defined relative to assumed parameters used in the stability analyses.

2. Performance Monitoring Guidelines for Dam Structure, Abutment and Foundation Seepage

Seepage through a dam or through the foundations or abutments of dams is a normal condition. However, increases in historically observed amounts of seepage, in the elevation of the phreatic surface in the dam, or abutments, in the uplift/seepage pressures beneath the dam or the appearance of transported material in the seeping water may be symptoms of a developing potential seepage related problems. The appearance of transported material in the seeping water of an embankment or soil foundation may indicate piping or seepage erosion which could lead to a failure.

a. Visual Observation and Leakage Weirs

The visual observation of new seepage or an increase in volume of seepage requires action be taken to quantify the problem and to watch for the presence of material being transported in the seepage. For example, if rapid increase in the seepage rate is observed, it may be a strong indication of a developing failure situation and emergency action must be taken. Visual observations of depressions or sinkholes in an embankment or upstream abutments or foundations are strong indications of piping occurrence.

To accurately monitor any seepage, it must be collected and passed through a weir for periodic measurement. A weir is a superior way for monitoring for the possibility of material movement for several reasons. It provides a continuous means for settling and trapping particles that may be piping or eroding as a result of the seepage flow. Episodic material discharge has been observed in several instances, thus a periodic check of seepage flow for material may not reveal whether the seep is actually moving material. Weirs also allow the material collected over a period of time to be measured and weighed. If weirs are used in an area where fines may be blown into the weir a cover is necessary. Also the weir should be routinely cleaned after each periodic measurement so the amount of new material between collections can be accurately assessed.

Flumes allow for accurate measurement of seepage rate but do not provide a means for collecting material. Regardless of the method used to measure the seepage rate (weir, flume or bucket and stop watch), a sample of the seepage water should be collected and allowed to settle out, at least overnight, to check for the presence of any suspended material (fines) being transported (piping or seepage erosion). Drainage pipes within a downstream embankment provide a convenient method for collecting and measuring seepage. Care must be taken that such pipes are properly filtered to prevent piping and if not it is even more important that the flow from the drain pipe(s) be routed through a weir to allow capture of any material being moved.

When new wet areas are observed on the downstream face of an earthfill dam, a determination needs to be made as to whether this water is emanating from a perched, more pervious zone in the embankment lying above a less pervious layer, or is indicative of a high phreatic surface. Wet areas and points of seepage exit should be marked on the dam face by large stakes so that any change with time / season can readily be assessed. Monitoring of vegetation (big roots can initiate piping) and rodent holes is critical. The determination of the nature of such seepage can usually only be confirmed by the installation of piezometers. The flow rate of such seeps should be monitored by weirs and checks made on transported material in the flow.

Although increases in seepage are generally considered to be more of an indicator of a potential problem, decreases in seepage (particularly in a concrete dam foundation but also within embankment dam foundations or drainage elements) may indicate that flow paths / drains are being blocked within or near their exit from the dam or foundation resulting in an increase in pressures. Thus when seepage decreases occur, checks should be made on piezometer or uplift gauges (if this instrumentation is present) and on the cleanliness of the drain elements.

The onset of significant increases in seepage may correlate with reservoir elevation reaching particular levels and this possibility should be reviewed at sites with significant seepage.

b. Piezometers and Observation Wells

A great benefit to understanding the potential for failure mode development related to seepage from a dam /foundation system is to develop an understanding of the relative pore pressures and direction of flow within and through the dam. If the pressures in the foundation (below the core) exceed those in the dam then the direction of flow indicated from the foundation to the dam and the possibility of piping of material from the dam to the foundation is remote. Conversely if the direction of flow indicated is from the dam base into the foundation then the physical possibility of piping from the dam through the foundation is indicated. The best way to determine this flow regime is to review the piezometric, observation well and seepage data.

Whenever there is concern for stability that may be sensitive to the phreatic surface or seepage forces in the abutment, foundation or embankment (such as in a rockfill dam with a wide central core), periodic measurement of water levels must be made. The measurement of seepage forces in abutments and foundations and particularly in a dam embankment is usually made by piezometers sealed to determine the water pressure in specific strata or zones. The phreatic surface in the abutments or foundation can be measured by observation wells, usually open tube pipes with long sensing zones and with only the top of the tube sealed to prevent surface water infiltration. If stratification exists in the abutment consideration for different piezometers sealed in the various soil horizons should be given.

c. Monitoring for Movement of Material (Piping)

Whenever seepage is observed emanating from / through the dam, foundation or abutments, periodic checks on movement of material should be made. A sample of the seepage water should be collected and allowed to settle out, at least overnight, to check for transported material (piping). Crest settlement surveys are an important source of early warning of piping failures, particularly in earth and rock-fill dams. Specific inspections to look for depressions or sinkholes, particularly in upstream areas, should frequently be made.

Increases in phreatic surface or seepage pressures in the foundation or abutments may also indicate that movement of material is occurring.

Where the foundation materials may be susceptible to solution from water of certain chemical properties, frequent checks on groundwater and reservoir water chemistry and on the chemical composition of seepage water should be made. Evidence of solution of foundation materials or strata requires prompt intervention.

d. Establishing Threshold Parameters for Seepage

Seepage through a concrete dam is usually monitored by observation and mapping (see Visual Observation). If seepage appears to be spreading or increasing in volume, then an investigation and action to reduce the seepage may be necessary. It is generally difficult to accurately determine the effects of through seepage on concrete dams.

Seepage through an embankment dam is usually monitored by observation, timed flows discharging from drainage pipes and weirs or other flow measurement devices. If seepage flow is increasing, then an investigation and action to evaluate the situation and determine if remedial action is necessary. Once a history of variation in seepage flow has been established with respect to season and reservoir level, then corresponding threshold parameter levels can be established that will trigger the need for further investigation and remedial action.

The location of the phreatic surface in the embankment or the seepage pressures at specific strata is determined by piezometers. Seepage through the abutments or foundation is similarly monitored. A steadily rising phreatic surface or increasing seepage forces should trigger a prompt review and, if necessary, remedial action.

Periodically, the measured phreatic surface or seepage pressures must be reviewed against those surfaces or pressures that were used for the most recent stability analyses. If the actual phreatic surfaces or seepage pressures exceed those used in the stability analyses, then a special engineering review must be initiated and remedial action may be required.

Seepage through abutments or foundation however can usually be collected and measured by weirs or other flow measurement devices. Once a history of variation in seepage flow has been established with respect to season and reservoir level, then threshold parameter data related to seasons and reservoir levels can be established that will trigger further investigation and remedial action.

3. Performance Monitoring Guidelines for Structure Movements and Stresses – Static and Seismic Loading

When possible distress of the dam structure itself is suspected as a result of observation of cracking, new leakage, movement monument measurements, or updated stress analyses, more detailed measurements of dam structural performance are required. Slab and buttress dam designs have typically been designed for in plane loading only. They are often inadequately reinforced and are incapable of resisting cross canyon earthquake accelerations.

It is difficult to determine stresses directly on an existing dam unless stress or strain meters or load cells were installed during the initial construction. Therefore, most performance monitoring is aimed at determining strains under varied loadings to calibrate stress analyses.

a. Precise movement surveys (surface) – horizontal and vertical.

   Additional surface monuments can be quickly installed and more frequent measurements made to obtain additional data.

b. Plumb lines

   Plumb-lines are very difficult to install on existing concrete structures. They also require vertical alignment that cannot be achieved in double-curvature arch dams unless galleries have been specifically placed to accommodate installation.

c. PMS - Tilt meters

   Measurements by tilt-meter are also useful. Tiltmeters can be installed on existing concrete structures and readings can be obtained quickly after installation. Tiltmeters are sometimes used instead of plumb-lines because they are easier to install and require little maintenance.

d. Load cells

   For direct measurement of loads in the dam, load cells must be installed during construction. While they can provide meaningful data, if they are not in the area of highest stress, they have limited usefulness. If post-tensioned anchors are used to improve stability, either in part of the dam (such as abutment blocks) or in the foundation, some anchors should have load cells installed to monitor their loss of tension so that retensioning can be performed as necessary.

e. Strain Gages

   Stain gages can provide valuable direct stress data if installed during construction. However, they are subject to the same limitations as load cells.

f. Seismographs

   Seismographs provide a valuable research tool when they are mounted on dams and triggered by significant earthquakes. They can provide response data for improving seismic stress models of the structure or for deformation models of an embankment. However, they are not useful for monitoring performance of dams but can confirm the response of the dam to an earthquake, e.g. crest amplification

g. Additional piezometers can be installed and more frequent measurement made to obtain additional data.

4. Performance Monitoring Guidelines for Erosion of Abutments or Foundations

Performance monitoring of embankment dams relative to washout is pertinent only with respect to ensuring the condition and levelness of the crest. Low spots, rutting or “built in” unevenness in the crest can exacerbate the potential for overtopping failure of an embankment dam. Spillway adequacy must be adequate to prevent this potential failure mode. In the case of embankment dams, the rule is to prevent overtopping, because it can lead to catastrophic failure.

a. Observation and Measurement of Deterioration of Abutments, Foundations, and/or Spillway Outfall/Energy Dissipater Areas

In order to monitor the deterioration of dam abutments, foundations, and/or spillway outfall/energy dissipater areas to assess the potential for washout failure, it is necessary to have data on the potential for flow over the abutments, including volume and frequency relationships, and specific data on large flows that would impacting the foundation.

The foundation, abutments, and spillway outfall areas should be surveyed and a profile of the foundation impact area of overflows, abutments and/or spillway outfall/energy dissipater areas made. Because survey markers in such situations will probably be lost in flow situations, the survey should be at precise station points along the abutments within the flow zone and on the downstream foundation offset from the crest of the dam. Such surveys should be repeated after major flows have occurred and the changes in the profile plotted and reviewed and the erosion potential quantitatively estimated. Utilizing the flow volume and frequency relationships, an assessment of potential failure due to washout can then be made.

b. Periodic Assessment of Geologic Conditions and Deterioration

In addition to the survey and assessment above, close geologic inspection of the foundation, abutments and/or spillway outfall/energy dissipater areas should be made including mapping of joints that could permit loss of foundation or abutment rock material. Such inspections should be repeated after major flows and the potential for washout failure made.

5. Performance Monitoring Guidelines for Leakage through Dam Joints or Cracks, Along Penetrations, Conduits and Structures

a. Periodic Visual Mapping of Leaks/Wet Areas on Downstream Dam Face

Using a downstream profile map of the dam, showing any visible vertical joints and horizontal joint or lift lines, make a periodic map of all cracks, leakage locations and seepage areas. The mapping should be supplemented by detailed photographs. If there are significant leakage locations or areas, such maps and photographs should be made at least semi-annually, at coolest and warmest times of the year, and regularly compared. Particular care must be taken to note areas of increasing leakage flow or extension of cracks.

b. Measurement of Seepage Quantity by Weirs, Flow Meters or Other Devices

Where it is difficult to determine if the quantity of dam seepage is increasing, various devices are available to measure flow. Unfortunately, they may be physically difficult to install on the vertical or overhanging face of an arch dam. They would generally only be utilized in cases of significant concern.

c. Periodic Visual Mapping of Leaks/Wet Areas on Downstream Dam Face

Using a downstream profile map of the dam, showing any visible vertical joints and horizontal joint or lift lines, make a periodic map of all cracks, leakage locations and seepage areas. The mapping should be supplemented by detailed photographs. If there are significant leakage locations or areas, such maps and photographs should be made at least semi-annually, at coolest and warmest times of the year, and regularly compared. Particular care must be taken to note areas of increasing leakage flow or extension of cracks.

6. Performance Monitoring Guidelines for Deterioration of Concrete

Concrete in dams sometimes deteriorates. Usually such deterioration is due to poor quality concrete having been used for construction. On older dams, alkali aggregate reaction is not uncommon. For dams at high elevations and in northern areas, freeze-thaw deterioration is a concern.

Concrete deterioration is more critical in Ambersen slab and buttress type dams where design stresses in the water retaining slabs and reinforced concrete beams are about 50% of the ultimate capacity utilized under normal loading. Concrete deterioration not only reduces the cross-section properties but also exposes the reinforcing allowing it to corrode and reduce cross-section.

a. Periodic Visual Inspection and Mapping of Deteriorated Areas.

Make a periodic map of all areas of deterioration whether caused by freeze thaw, alkali-aggregate reaction, or other mechanisms. The map should show any visible vertical joints, horizontal joints, lift lines, any loss of masonry elements or mortar from the joints. The mapping should be supplemented by detailed photographs. If there are significant deteriorated locations or areas, such maps and photographs should be made at least semi-annually.

b. Periodic Measurement of Deteriorated Areas

Measurements should be periodically made to assess the changes in the structure. In the case of alkali-aggregate reaction, periodic surveys of dam crest elevation should be made to ascertain the amount of swelling of the concrete. Also, cores of the expanded concrete should be taken at intervals and tested for compression and tension (if subject to tensile stresses.) The strength data obtained from the tests should be compared with the results of a stress analysis, to determine the adequacy of the structure.

In the case of freeze thaw or other deterioration mechanisms, the depth of deterioration should be periodically determined. If the area is quite localized, the depth can be determined by probing and measurements from the surface of unaffected areas. One technique is to install reference markers set in the deeper undisturbed concrete and periodically measure the distance from the end of the marker to the sound concrete.

7. Operations Procedures Common to all Dams

Mis-operation of a dam, either through equipment malfunction or human error, is often a viable potential failure mode. This section identifies some adverse conditions and associated defensive measures.

a. Human error

This includes all the site specific scenarios of mis-operation or failure to act. For example, if gate operation is required to pass a flood, but nobody raises the gates, the dam could fail.

Defensive measures could include additional specific training of personnel and emergency procedures exercises that are tailored to specific identified potential failure modes.

b. Equipment malfunction

Power failure - Anytime electrical equipment such as gate hoists, sensors, communications, etc is required for the safe operation of the dam, power failure can lead to a dam failure.

Defensive measures could include having standby power available at the site, and having manual overrides on critical equipment

Sensor/Telemetry malfunction - If the site is remotely operated, a sensor error or telemetry failure can lead to mis-operation or failure to operate.

Defensive measures may include performing regular telemetry testing, having redundant sensors for critical instrumentation, and having redundant communication systems.

c. Access failure

If personnel must be dispatched to a site to operate it in an emergency, they have to be able to get there. Large flood events are typically accompanied by severe weather that may make roads impassible and helicopter travel impossible.

Defensive measures may include having identified alternative routes to access the site or stationing personnel at the site prior to failure of access roads.

14.5 EMERGENCY PREPAREDNESS

The Independent Consultant should consider the various potential failure modes determined and review pre-planned procedures for dealing with potential emergencies. If any pre-planned measures need to be put in place, the Independent Consultant will make the necessary recommendations. These measures include necessary equipment, materials, etc.

APPENDICIES

Appendix A
Example Potential Failure Mode Descriptions

Operational Related Potential Failure Mode

The design flood was routed through Dam A by the hydrologic engineering consulting firm using the traditional means and assumptions and the capacities for the facilities provided by the owner. The dam was found to pass a sizeable portion of the probable maximum flood using the Main Spillway gates and the emergency spillways. Thus there was concern for the hydrologic deficiency but not great concern. However, examination at the site for potential failure modes revealed a significant potential for an Overtopping Failure mode due to the following factors:

- The emergency spillway bays were fronted by arch rings designed to be blasted away if the emergency spillway was needed. Discussions with the owner revealed that use of the emergency spillway in such a manner was highly improbable. This was due to the potential liability from such an action (a sizeable town is located just a mile or so downstream) and also due to the physical arrangement of the dynamite ports on the top of the spillway bays (it was likely that these would be underwater by the time a decision to use them was made). Further there were no plans or procedures in place to do the blasting.
- The first location for overtopping of the structure was immediately above the transformer yard. Overflow at this location would have resulted in loss of capability to pass flow through the turbines and while this flow was not relied on in the routing, the early shut off would have exacerbated the overtopping situation.
- Drawings were located for the secondary emergency spillway, which was referred to as a "fuse plug" spillway but this fuse plug actually had to be excavated by a dozer before it was functional. Operators at the site did not know the location of the spillway limits and had no procedures or equipment to initiate this spillway.
- Design crest elevations indicated that the concrete structures would be overtopped prior to the embankment structures. However, examination of survey data, settlement records and settlement projections (along with the physical location of the monuments relative to the crests) revealed that the low point for the project was currently an earthen saddle dam.

Piping Related Potential Failure Mode

The following potential failure mode was highlighted because the specific conditions at Dike 1 and 2 are such that this potential failure mode is physically possible and is one of the most significant potential failure modes definable at this site. Failure of the Dikes poses a high hazard, and diligence in monitoring for development of this potential failure mode is warranted.

Potential Failure Mode 1 - Dikes 1 and 2 - Seepage Erosion and Piping

During site investigation the foundation of these dikes was found to contain joints much more open than anticipated, based on pre-construction investigations. These joints provide a potential path for subsurface erosion of the Zone 1 material leading to an unprotected exit downstream of the dam. Although grouting was performed following construction (during the first filling of the reservoir) and the seepage levels were reduced, the fundamental potential failure mode remains). The presence of 4 to 5 ft^3 /s of seepage, which occurred during first filling, from a dike of moderate height and length attests to the possibility of open joints in the foundation capable of carrying adequate flow to result in erosion, and transport of eroded material downstream. The specific potential failure mode paths and the factors relative to the likelihood for the development of this potential failure mode are as follows:

Potential failure mode paths - there are two primary potential paths for seepage erosion/piping to take place through the foundation jointing and two of lesser likelihood. These are:

- Flow through the dike embankment across the Zone 1/ foundation interface. This could result in the Zone 1 materials eroding and being carried through the open joints to an unprotected exit downstream. (Failure would result if backward erosion (piping) through the Zone 1 materials reached the reservoir source. An ever increasing flow potential could then progressively enlarge the flow channel downstream of the point of erosion initiation in the core to an extent large enough to carry continually increasing flows).
- Flow under the foundation attacking the base of the Zone 1 material and removing it by seepage erosion through the foundation jointing

The other two potential flow paths leading to a seepage erosion/piping failure are (1) piping of the Zone 1 through the foundation alluvium and (2) seepage erosion of the foundation alluvium exiting through the open joints in the rock. These are considered to be of significantly lesser likelihood

Part 2 - Example Record of Likely and Not Likely Factors Identified for a Specific Potential Failure Mode

After each potential failure mode is identified and clearly stated and recorded the team brainstorms and discusses what conditions make this potential failure mode more adverse / more likely and what conditions about this potential failure mode are positive making it less likely or less significant. An example of the factors identified for the potential failure mode previously described above is presented below.

Factors increasing the likelihood of this potential failure mode developing include:

- the observation of very open joints in the foundation (greater than 2" wide)
- surface treatment was not provided to exposed bedrock
- grouting procedures used likely resulted in some of the most open joints remaining open due to the presence of the reservoir produced seepage flows during the grouting (this is most likely in the higher head, lower elevation portion of the dikes)

- grouting near the surface was likely not very effective, considering the method used
- large seepage flows are occurring, which can dilute and potentially mask observation of particles being carried by the flows. If an attack begins, large flows can erode large amounts of material relatively quietly.

Factors indicating less likelihood of this potential failure mode developing include:

- There has been no observation of any material being carried by seepage flows at these dikes.
- The Zone 1 appears to be clayey, very impervious, and not easily erodible.
- The placement of the Zone 1 cutoff-wall well upstream of the dike centerline creates a closer source for the reservoir's water, but a large portion of the dike would remain if an erosion path developed at the base of the cutoff.
- The lack of water in the toe drains is a likely indicator that the dikes have not saturated and that the foundation rock behaves as a drain keeping water away from or at low pressures at the dam/foundation contact.
- Seepage flows started downstream of the dikes prior to the water reaching the upstream toe of the dikes. This indicates the pervious nature of the foundation and the likelihood that a large portion of the seepage water passes beneath the dikes (relatively independent of it).

Appendix B
Potential Failure Mode Identification Cover Letter and Questionnaire

POTENTIAL FAILURE MODE IDENTIFICATION

The PFMA concept provides that the identification of potential failure modes with potential effects and consequences be prepared with input from all persons with data and information relevant to the design and performance of the dam. Your input is requested. This memo tells you all about how it will work and what your role is.

*** Individual Input to Potential Failure Mode Analysis ***

<u>How is this special effort going to work?</u>

The idea is to produce the potential failure mode analysis efficiently without sacrificing the specific knowledge, information and opinions of people who have worked on the dams in the past or are working on them at present. The information and knowledge you have will be collected in three ways as enumerated below. Please note that the potential failure modes developed as part of this concentrated effort will be based on available data and information. We do not expect you to do any additional studies. However, you may suggest what additional study may be valuable as part of a Safety of Dams Review for this dam.

<u>How will we get your input?</u>

1. Through a questionnaire completed individually and designed specifically to obtain the information needed to help develop the potential failure mode analysis.
2. Through core team review of all work that has been prepared for the dam.
3. Through a round table discussion with available team members following completion of 1 and 2 above.

The concentrated effort will allow efficiency in preparation and consistency in the product.

Please complete each portion of the attached questionnaire for which you feel you can make a contribution. Feel free to review any relevant portion of your past work on the project to refresh your memory prior to completing the questionnaire. When you have completed the questionnaire send the completed document to ------------

Thanks for your help.

POTENTIAL FAILURE MODE QUESTIONNAIRE

for ________________________ Dam

Name ____

Team Members Experience / Role ______________________________________

Phone _________________

Date Due _______

Part 1 - Potential failure modes

"Failure" is considered to be something which causes uncontrolled release of the reservoir (or a portion thereof).

I. What potential failure modes do you consider are of specific concern at this project? Please provide specific description of the potential failure mode, including location of the area of concern.

Potential failure mode 1.

Potential failure mode 2.

Potential failure mode 3.

Part 2 - Performance Observation - For each potential failure mode identified in Part 1

II A. Please describe as specifically as possible what may be observed or measured to verify that performance is okay relative to the potential failure mode, or that conditions that are conducive to initiation of the potential failure mode have become present or that "activation" of the potential failure mode appears to be taking place. Please suggest how that may be observed or monitored.

II B. Is the monitoring or observation you suggested currently in use at the dam?

III. If you have visited the site either as part of an official inspection or a general site visit, please identify any conditions that are noteworthy from the standpoint of performance of the dam.

Appendix C
A Typical Potential Failure Mode Analysis Session

Step by Step Description of a Typical Work Session

- Identifying Key Technical Back up Information Needed
- Typical Sequence of Brainstorming Activities
- Key information to document during the process

The intent of this appendix is to describe what is done in a typical PFMA session. This is done so participants will know what to expect and so that all the right information and data will be on hand and the people needed are there or on call.

Owner / organization prerequisite work: - Gather all background materials for review prior to the session and have available at the session

Required individual advanced preparation activities:

1. Core team members have read all background materials
2. All participants have read a general background package (inspection report and / or standards based engineering dam safety report) to become familiar with or to recall the project elements and issues.
3. All participants have completed / considered questionnaire on identification of potential failure modes.
4. Inspector or instrumentation group has instrumentation and surveillance data updated and ready for review by core team prior to meeting
5. Project leader has references available in meeting room – this includes:
    - all engineering reports and key feature drawings (large scale)
    - construction photos and construction / design history data ,
    - flood frequency data and routings and earthquake loading data
    - data on consequences and emergency preparedness
    - inspection reports and instrumentation and surveillance data.

Begin Session

I. Adequacy of Project Documentation - Discuss adequacy of documentation provided for the exercise and determine if any deficiencies exist for specific potential failure modes. Determine if sufficient information exists to adequately perform the Potential Failure Modes Analysis for the project. Document your findings regarding adequacy or deficiencies in project documentation.

II. Potential Failure Mode Identification – Go loading by loading and feature by feature – Have drawings or sketches of features - Typically start with flood loading since it is the easiest for all to understand and sets out the reservoir loading conditions ----

Flood loading:

- go over all the key data - size and frequency of floods analyzed, routing data
- show crest elevations of key features and amount of overtopping / freeboard for each flood routed – discuss slope protection, crest condition , discharge locations
- Examine potential effects / potential failure modes / adverse conditions for dam structures and spillways / outlets. *Note: go over each structure to see if any potential failure mode is evident.*
- Candidate (suggested) potential failure modes are called for and means /steps to failure are discussed – decision is made whether or not to consider as a potential failure mode.
- If a suggested potential failure mode is considered, the potential failure mode is clearly described – then the reasons why the candidate potential failure mode is more or less likely to develop (adverse and positive factors) are listed on flip chart. Based on this discussion the team classifies the potential failure mode (highlighted, considered but not highlighted, etc.)
- Breach formation character and rate of failure are discussed. Consequences of a flood related failure and of operational spillway discharges are discussed.
- Failure scenarios (exposure conditions and warning aspects– detection, decision to warn – dissemination of warning - evacuation, etc) are discussed. Anticipated response is reviewed with field / site personnel – in reality this exercise is looking for "potential failure modes in the preparedness arena".)
- Opportunities to achieve risk reduction – structural or non – structural and ways to improve detection via instrumentation or surveillance are identified and listed
- Data / information needs are discussed and identified.

Reservoir loading / Static load:

Repeat above process – key changes or additions or points of emphasis in examining this loading are noted below:

- Discuss annual and historic pattern of reservoir loading
- Discuss performance history of each feature
- Discuss any instrumentation clues to potential failure mode
- Discuss Geologic / foundation rock and soils relationship to structures – examine for potential failure modes – for concrete dams discern whether or not a foundation analysis based on adequate engineering geologic has been completed
- Trace (from a projection) on a white board a sketch of the cross section of each structure to be evaluated in turn. Sketch each potential failure mode as suggested to enable brainstorming / developing / understanding. Plan or profile sometimes needed as well.
- A list of the reasons why and why not these potential failure modes are likely to occur are discussed and recorded – This discussion is very important in evaluating significance / category of potential failure modes suggested (which is the next step)
- Based on this discussion the team classifies the potential failure mode (highlighted, considered but not highlighted, etc.)
- Evaluate failure scenarios for each significant potential failure mode – (these scenarios do not have the same warning associated with flood or earthquake loading)

Earthquake loading

Repeat above process – key changes or additions or points of emphasis in examining this loading are noted below: (Note –dynamic loading follows static loading because some of the potential failure modes are similar – can examine the degree additional loading may impact static condition.)

- go over all key magnitude and frequency data for site (historic and tectonic study data) and site attenuation or amplification data to get sense of the loading likelihood.
- review any dynamic analyses
- examine what it takes for failure to occur – i.e. does damage result in failure
- compare structures at site to case histories of earthquake related failure

Consider any other loading relevant to site:

Ice, avalanche, landslide, etc. – Repeat process used for other loadings

III. Make final team assessment

1. Significant Potential Failure Modes (Highlighted) in each loading category and Summarize / Rank
2. Potential failure modes considered but not highlighted
3. Potential failure modes considered but lacking key data or information to allow designation of significance – identify data needs
4. Failure Modes ruled out

IV. Review possible risk reduction / instrumentation / surveillance opportunities identified for all potential failure modes considered

Place the identified into two categories:

1. Possible alternative mitigation actions to investigate, and
2. Actions to be considered by the Independent Consultant for implementation by the owner.

V. Identify and Record – "Major Findings and Understandings"

The major findings and understandings achieved as a result of the session (give team members a few minutes to think about these before listing) along with the description of each potential failure mode considered should be written up and distributed to participants shortly after the PFMA session.

Appendix D
Suggested General Format for Potential Failure Mode Analysis Reports

(For further guidance and example see a typical report developed from this outline – these reports may be obtained from any FERC Inspector)

I. Introduction and Background

Purpose / description of study

II. Brief Description of Dam and other Key features of project

III. Major Findings and Understandings from study

IV. Potential Failure Modes Identified

(For each potential failure mode identified there would be:

- A Detailed Description of the Potential Failure Mode / Adverse Consequence
- A listing of adverse / likely factors and a listing of and positive/ not -likely factors
- The likelihood category selected by the team for that potential failure mode
- A description of rationale used for selecting that category (i.e. – the factors with the greatest weight)

The presentation of potential failure modes would be grouped according to the 4 likelihood / importance categories.

1. Highlighted
2. Considered but not highlighted
3. Information needed to allow classification
4. Ruled out-not physically possible/extremely remote

Other Considerations – thoughts / ideas / concepts / future changes that were considered related to potential failure modes that were brought up and discussed but not developed by the PFMA team as a potential failure mode (That is - there was no detailed description of the Potential Failure Mode / Adverse Consequence and a listing of adverse / likely factors and a listing of and positive/ not -likely factors was not developed) should be documented in this section such that future teams will know what items were considered and why they were not carried forward at this time.

V. Likely Consequences of Each Potential Failure Mode

- Flood related potential failure modes
- Normal Operating related potential failure modes
- Earthquake related potential failure modes
- Other condition potential failure modes

VI. Potential Risk Reduction Actions Identified

Note: This is often effectively included as a part of section IV under each potential failure mode.

- Surveillance and monitoring enhancements
- Risk Reduction measures to evaluate
- Investigations / analyses needed
- Data and information needed to collect / prepare for decisions on prioritization of dam safety actions

VII. Other considerations related to study

VIII. Summary of potential actions identified in the PFMA with respect to Performance Monitoring (Instrumentation and Visual Surveillance)

IX. Summary and Conclusions

Appendix to Report

Key supporting data and information and references, Figures, Sketches, Photos made during field review showing key elements of dam and auxiliary features should be included along with any photos that show conditions leading to potential failure modes,

Appendix E
Major Findings and Understandings - Example Write Up

Given below is an example write up of the major findings and understandings gained from a Potential Failure Mode Analysis for a project consisting of a Main Concrete Dam incorporating a Power Station and Two Auxiliary Embankment Dams. Although this was an actual study and the actual findings, the names of the dams and the river in the example are not the real names.

- Currently in the event of a very large flood on the Blue River, approaching the PMF, overtopping failure of Auxiliary Dam 1 is the main point of vulnerability at the project. This is because the crest of Auxiliary Dam 1 it is at a lower elevation than is the crest of Auxiliary Dam 2. In the event of Auxiliary Dam 1 failure, peak discharges downstream would nearly triple (from about 1900 m^3/s at failure to 5700 m^3/s at breach) and the consequences of failure of Auxiliary Dam 1 would be high (life loss potential and large economic losses). On the other hand if Auxiliary Dam 2 were to be established at a lower elevation than Auxiliary Dam 1 and thus allowed to fail from overtopping the effects and consequences of overtopping failure would be significantly less. Auxiliary Dam 2 failure peak discharges downstream are estimated to only be slightly larger than flows resulting from the PMF (from about 2100 m^3/s at PMF to 2400 m^3/s at breach). Several measures to achieve overtopping failure risk reduction are identified in the report and the best alternative should be selected after an appropriate risk management evaluation. However, the Potential Failure Mode Analysis team emphatically concluded that it is essential that as long as the potential for overtopping failure of the earthfill dams exists, Auxiliary Dam 2 should be established at a lower elevation than Auxiliary Dam 1.

- Dam failure as a result of piping is a physically possibility at Auxiliary Dam 1 as the result of one or more potential flow paths. Although there is no unequivocal physical evidence that piping has occurred or will occur in the future, the nature and relationship of the materials in the dam and foundation, the water level and piezometric observations, and the performance of the structure (observation of surface seepage and a depression at the toe) allow for this possibility. Further the surveillance and instrumentation have not been extensive enough to rule out the possibility that piping episodes (turbid water or particle transport) have occurred, and even if they had been transport of material could occur subsurface and thus not be amenable to observation. The consequences of a “sunny day” piping failure of Auxiliary Dam 1 would be high with a greater life loss potential due to the possible lack of advance warning. From the standpoint of the Potential Failure Mode Analysis Team, awareness of this potential piping condition is a key finding of the study as this potential failure mode is the most significant structural vulnerability found at the project. Several risk reduction measures, both structural and non-structural were identified and should be considered in the risk management evaluation of the project.

- A potential foundation failure mode identified for the Main Dam was the only PFM of significance identified for this structure. Although, this foundation potential failure mode is considered physically possible it is highly probable that a foundation stability analysis would show that the factor of safety against failure is quite high and thus risk reduction measures would not be required. Thus, the Potential Failure Mode Analysis team considers that analysis rather than consideration of remedial work is the appropriate initial course of action relative to this potential failure mode.
- The Potential Failure Mode Analysis team considered that failure of the Main Dam by overtopping was not a realistic potential failure mode and should not be highlighted. However, the main dam would be the first structure to be overtopped during a major flood condition, well before either of the earthfill dams. This would occur for the PMF but also for floods significantly less than the PMF. It was determined in the Potential Failure Mode Analysis that overtopping of the main dam would result in significant damage to the power facility and that much if not all of this damage is preventable. For example the cable trays are at crest level on the downstream side of the dam and would be destroyed with mild overtopping. Also water flowing over the top of the dam would currently spill directly on the power plant and likely knock that plant out of service and cause considerable damage. This flow could be directed away from the plant area. Thus, main dam overtopping, while not a potential failure mode, would be a significant incident for the Owner and the Potential Failure Mode Analysis team considers that risk reduction measures to reduce the impact of the overtopping of the main dam should be evaluated.

This example was chosen for brevity – only the most significant of the findings are recorded – examples which provide significant greater detail are available from a FERC inspector)

Appendix F
Estimated Time Requirements
(PFMA items only – not subsequent Part 12D activities)

The typical time requirements for the major activities in the set up and completion of an initial PFMA are as follows:

Task 1 - Advance preparation

Facilitator – Consult with and provide information/guidance to owner – ½ day

Owner – Assemble Materials, notify participants / send out advance packet of material, setup facility and make arrangements - 3 days

Task 2 ----Visit site, review materials, carry out PFMA session

Owners core team representative – travel to and visit site with core team – review materials and participate in session – 3 days

Independent Consultant – Facilitator – FERC representative – as above - 3 days each

Task 3 – Documentation of study

Independent Consultant- prepare draft of Major Findings and Understandings, distribute for review and comment. Prepare draft of PFMA report distribute for review and comment and finalize - 5 days

Facilitator – peer review and edit of Major Findings and Understandings, PFMA draft and final report - 1 ½ days

Owner's representative – review and comment on report – ½ day

Appendix G
Potential Failure Modes Analysis (PFMA)
Dam Safety Evaluation Process

Task No.	Description	IC Report	Responsibility
1	**Data Assembly:** Assemble all available background data for the dam and appurtenant works for the project. These data should include investigation, design, and construction reports, construction photos (and all other project photos), construction and as built drawings, geologic reports, construction inspection reports by the owner / designer and those by state and federal agencies, seismic studies, most recent flood studies, stability and/or stress analyses, lab test results on rock, soil and concrete, instrumentation monitoring data and visual inspection reports, periodic dam safety reports including all Part 12 D reports, Emergency Action Plans, photographs of key elements and features showing present condition and any remedial work. Prepare summary informational packet describing the dam / project (e.g. – the most recent Part 12D)	**Chap 2, Chap 8 & App B**	**Owner, IC**
2	**Initiate PFMA:** Establish "Core Team" to carry out PFMA - Experienced PFMA Facilitator, Independent Consultant (IC), Owners representative/PFMA Coordinator, FERC Inspector. Also determine who the individuals will be that will support / attend the PFMA, dam engineering geologist, mechanical-electrical specialists (if needed for gate/valve issues), consulting engineering staff, operating staff responsible for surveillance and maintenance of each specific dam, project manager, etc. Send out Potential Failure Modes Analysis Questionnaire *(Ref: Appendix B – Forthcoming PFMA Guidance Document)* to all participants in advance of the PFMA to get all participants "thinking potential failure modes" and gathering relevant materials and information that may be helpful to the session. Send out a summary informational packet to the core team to familiarize them with the project before their site review and to familiarize / provide review to all	**Chap 3**	**Owner, FERC, IC, Facilitator**

	other participants before they come to the PFMA session		
3	**<u>PFMA Field Review:</u>** Physically inspect all aspects of the dam structures and appurtenances (relevant to dam safety). Try to observe / discuss potential circumstances / conditions that could lead to a potential failure (structural or operational). Discuss operations with plant operators / site personnel. The PFMA field inspection is to familiarize the core team with the project features and conditions so that they can effective carry out the PFMA. It is not a substitution for the Part 12 D field inspection by the IC, which is to determine the condition of all safety aspects of the dam and power facilities. *(Note: Allow approximately one-half day per dam. May be more depending on the complexity of the project.)*	**Chap 3**	**Core Team Geologist, Operating Staff, Specialists**
4	**<u>PFMA Data Review:</u>** Assemble and review data on the dam. Should be at convenient location considering location of site/data/PFMA. Assemble in a group setting for efficiency in sharing the collected data and to provide a "captive" condition to ensure that the material is reviewed by all the core team members. Also being together allows for collaboration on items that may need clarification for the entire core group. The team geologist should ensure that the relevant geologic data is available for core team review and the geologist should also review this material personally. *(Note: Allow one day for the review plus evening of site review and evening before PFMA as necessary. This review is essential to an effective PFMA.*)	**Chap 3**	**Core Team**
5	**<u>Facilitated Potential Failure Mode Analysis:</u>** Discussion lead by Facilitator of candidate potential failure modes (PFMs) for Flood, Earthquake and Normal Operating conditions for each of the structures. Develop (describe events and conditions from initiation to breach or other adverse outcome) each Potential Failure Mode considered realistic and credible by the PFMA team then brainstorm and list all the positive factors that make the potential failure mode less likely to occur and all the adverse factors that make the potential failure mode more likely to occur. Discuss consequences of each PFM (and / or at end of PFMA discuss consequences and response to	**Chaps 3, 4 & 6**	**Core Team, Geologist, Operating Staff, Specialists as needed**

	potential failure). After discussion of each PFM, categorize the potential failure mode (see Table 1 PFMA Guidance Document). Review the categorizations at the conclusion of the PFMA. During each PFM discussion, identify possible risk reduction actions including – monitoring, surveillance, investigations, analyses, remediation (structural or non-structural) and operational procedures & maintenance programs. For each Category I-III potential failure mode a performance monitoring program (PMP) must be identified. Performance monitoring can vary from periodic visual inspections, to continuous recording instrumentation and may include monitoring of weather forecasts and monitoring of earthquake activity. To complete the PFMA solicit individual input on the Major Findings and Understandings (MFU) reached during the PFMA process (all the key things learned or more fully understood during the 2-3 day effort). All the input should be recorded on flip charts (hand written) and may also be recorded electronically (laptop). Ensure that all participants have their input/concerns listed. Photograph hand written charts. End PFMA meeting.		
6	**Draft MFU:** IC prepares (amplifies/fleshes out) items identified as Major Findings and Understandings (MFU) of the PFMA, emails it to Facilitator for peer review (edits, additions and comments). IC then modifies MFU to include Facilitator comments.	**Chaps 3, 4 & 6**	**Facilitator and IC**
7	**MFU Review:** IC then emails MFU to core team and geologist. *(Note: Owner may distribute to staff for further input).* All review and comment /send email to IC. IC modifies MFU to include comments.	**Chaps 3, 4 & 6**	**Core Team, Geologist**
8	**Draft PFMA Report**: IC prepares draft PFMA report using FERC report outline and emails draft to facilitator for peer Review. IC modifies PFMA report to include facilitator comments. IC sends peer reviewed draft PFMA report to Core Team and Geologist. All review and email comments to IC. IC modifies PFMA report to include all comments (some discussion between IC and others is usually	**Chaps 3, 4 & 6**	**Core Team, Geologist**

	needed to achieve final agreement). The final report must specify the PMPs for all Category 1 and 2 PFMs.		
9	**<u>Finalize PFMA Report</u>**: IC prepares final PFMA report as agreed with Owner. Facilitator Peer reviews final report. Owner forwards final report to FERC with copies to Core Team. Review and comments on the MFU and PMFA drafts typically average about one day for the facilitator and ½ day or less for each Core Team member and the geologist.	**Chaps 3, 4 & 6**	**IC, Owner, Facilitator**

Appendix H
Part 12D Safety Inspection Report Outline

Table of Contents

The Table of Contents must show the inclusive page numbers for each section and subsection. If any subsection is not applicable, include the subsection with a statement of "Not Applicable" and an explanation of the reason(s) why.

For licensed projects that include multiple independent dam and powerhouse developments, separate Part 12D reports should be published for each development.

1. **Executive Summary**
2. **Project Description**
3. **Discussion of Potential Failure Mode Analysis Report**
4. **Performance Monitoring and Visual Surveillance with Respect to Potential Failure Modes**
5. **Field Inspection**
6. **Operations and Maintenance Programs Relative to Potential Failure Modes**
7. **Assessment of Supporting Technical Information Document**
8. **Recommendations**

List of Tables (with location)

List of Figures (with location)

List of References

<u>Appendices for Part 12D Inspection Report</u>

A. **FERC Letter Requiring Part 12D Inspection**

B. **FERC Letter Approving Part 12D Consultant** - Include date of current report outline provided by FERC

C. **Project Figures**

Only provide general overview drawings necessary to understand the project and items discussed in the report. If figures are placed in Section 2, provide a statement that figures may be found in Section 2. Optionally, if the STI is bound with the Part 12D report provide a statement that figures may be found in the STI document; duplicate drawings from the STI do not need to be included in the Part 12D report proper.

Additional detailed drawings will be included in the Supporting Technical Information document.

D. Instrumentation Monitoring Data Plots

List each figure and drawing included in the report. Optionally, instrumentation plots may be placed in Section 4 of the report and a statement included in Appendix D that the plots may be found in Section 4.

E. Inspection Photographs

Optionally, some or all of the photographs may be included in the appropriate sections of the report. If photographs are included within the report, provide a list of the photographs and the corresponding page number in Appendix E.

F. Inspection Checklists (Optional)

G. Operation and Maintenance Documentation (If required)

1.0 Executive Summary

The executive summary is intended to be a concise summary of the Part 12D Independent Consultant's findings, assessments, conclusions and recommendations. The information can be provided in narrative and/or bulleted format.

1.1 General (include *brief* project description)

1.2 Summary Assessment of the FMA report

1.3 Summary of Field Inspection Findings

1.4 Summary of O&M status

1.5 Summary Assessment of "Supporting Technical Information" document

Note: Specifically identify any new calculations conducted by the Part 12D Independent Consultant for this report.

1.6 Conclusions

Provide a summary of conclusions from each section of the report listed by section.

1.7 Summary of Recommendations

Provide a summary of conclusions from section 8 of this report.

1.8 Certification

Note: By signing this document, the Part 12D Independent Consultant is stating that the entire report has been developed by and under the direction of the undersigned. The Part 12D Independent Consultant shall make a clear statement that he/she generally concurs with the assumptions, methods of analyses, and results of all studies documented in the report. The Part 12D Independent Consultant is thus taking responsibility for the Part 12D report contents as a Professional Engineer. It is not required to repeat this statement in each section or sub-section of the report.

1.8.1 List of all field inspection participants

1.8.2 Reference to FERC Order 122 dated March 1, 1981 and paragraph 12.37 (c) (7).

1.8.3 Signature(s) of Part 12D Independent Consultant(s)

1.8.4 PE Stamp

See Appendix A: **FERC Letter Requiring Part 12D Inspection**

See Appendix B: **FERC Letter Approving Part 12D Consultant** - (Include date of current report outline provided by FERC)

2.0 Project Description

2.1 Brief Project Description

For each major element and ancillary structure, provide a brief description of the type of structure, general dimensions, etc. The detailed project description will be in the "Supporting Technical Information" document.

For multi-project or development licenses, include a brief outline of how this site fits with the other projects.

2.2 Hazard Potential Classification.

Based on views from the dam, other project works inspected and discussion with the licensee, document any changes in upstream or downstream conditions that might affect the Hazard Potential Classification. Review with the licensee the methods and assumptions used to develop the IDF. If the IDF is less than the PMF, the IC should confirm that the IDF is still valid based on an assessment of the downstream conditions as noted above.

2.3 Summary of Standard Operating Procedures

2.3.1 Purpose of Project (Run of river, storage, flow augmentation, flood surcharge storage, control reserve, pumped storage, etc.)

2.3.2 Reservoir rule curves by season (include operating restrictions if any)

2.3.4 Standard gate operation procedures (lead and following gates, emergency power systems, etc.)

2.4 Modifications Conducted for Project Safety

Document any modifications to project works since the last Part 12D inspection that have been done to improve project safety. (i.e.: spillway gates reinforced, seepage drain, berm added, crest raised, post-tensioned anchors installed, foundation drains or relief wells cleaned, etc.). In the next Part 12D Safety Inspection Report, these items will become part of Section 2.1. This information should be fully described in the updated "Supporting Technical Information" document submitted with the Part 12D report.

Do not include routine maintenance such as unit overhaul, gate painting, etc. Note, that generators, transformers, and transmission facilities are excluded from the Part 12D program under 18CFR subsection 12.35.

2.5 Flood History

2.5.1 Flood of Record, PMF, IDF

2.5.2 Zero freeboard spillway capacity

2.5.3 Peak spillway discharge during last five year period

2.5.4 Peak reservoir elevation during last five year period

2.6 Conclusions (If any)

See Appendix C: **Project Figures** (Note: If the STI is bound with this report, do not duplicate figures)

3.0 Discussion of Potential Failure Mode Analysis Report

Do not include security issues in the Part 12D report. For licensed projects that include multiple independent dam and powerhouse developments, separate PFMA studies and reports should be made each development.

3.1 General

Identify the team members, and their affiliations, who developed the comprehensive Potential Failure Modes Analysis (PFMA) or its update. Note that the process was in accordance with FERC Engineering Guideline Chapter 14.

3.2 Assessment of Potential Failure Mode Analysis Report

3.2.1 General

List the viable potential failure modes identified in the PFMA report. These would generally be Category 1 through Category 3 events. Provide an assessment of the reasonableness and completeness of the failure mode scenario and whether the PFMs identified have a real possibility of occurrence. Potential Failure modes should be listed in order of importance.

3.2.2 Potential Failure Mode Scenarios

Each realistic potential failure mode description should include the sequence of conditions and events that would lead to the failure mode.

- PFM 1. (i.e. Internal erosion, piping)
- PFM 2. (i.e. Seismic induced deformation)
- Etc.

3.2.3 Assessment of Mitigation Actions for Each Potential Failure Mode

For each potential failure mode, assess the actions that can be taken to mitigate the developing potential failure. (This would come from the PFMA report).

- PFM 1
- PFM 2
- Etc

3.2.4 Assessment of Monitoring Program for Each Potential Failure Mode
For each potential failure mode, assess the monitoring (visual and instrumentation) that exists or is recommended in the PFMA report that will warn of development of the potential failure mode, of adverse performance, or of an impending failure condition.

- PFM 1
- PFM 2
- Etc

3.2.5 Are there other potential failure modes that have been identified and addressed in this report or that should be assessed?

3.3 Supporting Documentation

Has the Licensee archived all materials and documents that were utilized in the PFMA session?

3.4 Conclusions

See "Supporting Technical Information" document: **Potential Failure Mode Analysis Study Report** (Update as appropriate)

4.0 Performance Monitoring and Visual Surveillance with Respect to Potential Failure Modes

Note: Review and Assessment of performance monitoring programs must always be done from the point of view of potential failure modes. Although the primary assessment is with respect to the potential failure modes identified in the PFMA study, the Independent Consultant must determine if there are potential failure modes not previously addressed or not adequately considered.

For the purposes of this section, a Threshold value is the value used in the analysis or design, or is established from the historic record. An Action Level is the instrument reading that triggers increased surveillance or an emergency action.

4.1 Operator's Surveillance Program

Daily/weekly operator's inspections and reports.

4.2 Active Instrumentation

This will vary by project. Discuss only the instruments actually at the project. Is instrumentation in accordance with Chapter 9 of the Engineering Guidelines?

4.2.1 Piezometers

4.2.2 Weirs

4.2.3 Settlement/alignment monuments

4.2.4 Crack gages

4.2.5 Upstream river and/or rain gage stations

4.2.6 Headwater/tailwater (alarm systems)

4.2.7 etc.

4.3 Threshold and Action levels

For each instrument, or group of instruments as appropriate, provide a table of Threshold and Action levels as defined above. If the information is included in the STI provide an assessment of the information.

4.4 Reading procedures/frequency

4.4.1 Data acquisition and evaluation (manual/automated)

4.4.2 Data evaluated in a timely manner by a qualified engineer

4.4.3 Spurious readings (are spurious readings confirmed or explanations provided)

4.4.4 Readings compared to Threshold and Action levels defined for each instrument

4.5 Assessment of Instrumentation Data and Performance Monitoring Programs Relative to Potential Failure Modes

Include newly identified potential failure modes

4.6 Conclusions

Instrumentation plots may be presented in either Appendix D or Section 4 of the Part 12D report. If the plots are included in Section 4, include a statement in Appendix D that the instrumentation plots may be found in Section 4.

5.0 Field Inspection

5.1 Field Inspection Observations

For each element of the project (i.e.: spillway, earthfill embankment, gravity section, intake, powerhouse, conveyance system, etc.), observe and report visual observations of the following issues as appropriate. Include photographs of significant project features and observations. If an inspection checklist is used, include a copy of the checklist in this section. A site specific inspection checklist should be formatted to include specific visual surveillance items identified in the PFMA.

The intent of this section is to highlight changed conditions for the report reviewer, not to document unimportant or minor details.

The report should be in text format by structure or element addressed individually. For each structure or element of the project, The Part 12D Independent Consultant should consider the following items:

- Settlement
- Movement – including abutments (cracks or other signs of distress or change)
- Erosion
- Seepage/Leakage
- Cracking
- Deterioration
- Spillway gate Operation/Standby Power (At a minimum, the Part 12D Independent Consultant needs to review the licensee's annual certificates of spillway gate operation and interview project operating staff to assure that emergency backup systems work and that operating personnel know how to use them.)
- Outlet/Sluice Gate Operation
- Water conveyance systems (canals / flumes / penstocks / tunnels / surge chambers, emergency bypass or closure systems, etc.)
- Foundation Drain/Relief Well Operation
- Evidence of high artesian or uplift pressures (structures / foundations / abutments)
- Observations of sediment transport (piping evidence)
- Observations of seeps, wet areas, springs, green grass
- Other Pertinent Observations

5.2 Status of Response(s) to Recommendation(s) in Last Part 12D Report.

5.3 Field Observations with Respect to Potential Failure Modes

Document field observations pertinent to each potential failure mode noted in Section 3

5.4 Adequacy/Operation of Public Alert Systems

Note: Are upstream spillway warning buoys, and downstream sirens and lights operable?

5.5 Conclusions

See Appendix E: **Inspection Photographs** (Optionally, some or all of the photographs may be included in the appropriate sections of the report. If photographs are included within the report, provide in Appendix E a list of the photographs and the corresponding page number)

See Appendix F: **Inspection Check List** (optional)

6.0 Operation and Maintenance Programs Relative to Potential Failure Modes

Do not include security issues in the Part 12D inspection report. If observations of significant O&M issues are made, include in report for possible new potential failure mode analysis.

6.1 Summary PFMA identified O&M issues (from PFMA report)

6.2 Operation and Maintenance Procedures

6.2.1 Communication/Response

Address adequacy and reliability of remote monitoring, communication and control systems (Operations / Instrumentation / Telemetry – Do the systems provide adequate reliability and redundancy? Can a specific gate, valve or other project component be operated remotely on demand?)

6.2.2 Electrical/Mechanical Systems

- Spillway Gate Motors (line/line voltage, amperage draw)
- Standby and Redundant Power Sources
- Manual/Remote/Automatic Operation of Gates and Valves
- Gate Operation Sequence
- Icing protection (heaters/bubblers/reservoir level restriction)

6.2.3 Human Factors

- Adequate Staff for Emergency Response (Multiple Sites)
- Reliable Access Routes (winter/storm conditions)
- Training
- Electricians/Mechanics/Laborers
- Adequate Time to Respond
- Call Out Systems (time for crew to reach site after call out)

6.3 Assessment of O&M Procedures Relative to Potential Failure Modes

6.4 Conclusions

See Appendix G: **Operation and Maintenance Documentation**

7.0 Assessment of Supporting Technical Information Document

The purpose of this section is for the Part 12D Independent Consultant to assess the contents of the "Supporting Technical Information" document compiled by the licensee.

7.1 Potential Failure Mode Analysis Study Report (Include a statement referring to Section 3 for a discussion of the Potential Failure Mode Analysis)

7.2 Project Description and Drawings

7.3 Construction History

7.4 Standard Operating Procedures

7.5 Assessment of Geology and Seismicity

7.6 Assessment of Hydrology and Hydraulics

7.7 Assessment of Instrumentation

7.8 Assessment of Stability and Stress Analyses of Project Structures

7.9 Assessment of Spillway Gates

7.10 Pertinent Correspondence Related to Safety of Project Works

7.11 Status of Studies in Process and Outstanding Issues

7.12 References

7.13 Conclusions

The Licensee is responsible for compiling the "Supporting Technical Information" (STI) document.

The initial STI should be provided to the Independent Consultant and three hard copies and two digital copies shall be submitted to the FERC. As new information is obtained, or modifications are made to the project, the licensee will update this document as required. Updates to this document shall be provided to the current FERC Part 12D Independent Consultant for review, to the FERC and to other document holders. Document holders should be requested to insert the updated pages in the STI, and add the revision to the revision notice log in the front of the STI.

Except for the initial submittal of an STI document, if no significant changes have been made to the STI since the prior Part 12D Inspection report, either a digital copy of the most current STI in *.pdf, *.jpg, *.tif, or other acceptable formats (check with the FERC for acceptability of alternative formats prior to submittal) or a hard copy of the STI shall be included with the Part 12D report. For small projects, the STI document may be bound with the Part 12D report.

8.0 Recommendations

Each Recommendation should be identified as a maintenance or dam safety item and include a schedule for completion/implementation.

Each section of the report should be included for completeness. If there are no recommendations pertinent to a given section of the report include that section with a "None" comment.

8.1 Project Description

8.2 Potential Failure Mode Analysis Report

8.3 Performance Monitoring and Visual Assessment with Respect to Potential Failure Modes

8.4 Field Inspection

8.5 Operations and Maintenance Programs Relative to Potential Failure Modes

8.6 Assessment of Supporting Technical Information Document

APPENDICES

List of Tables (with location)

List of Figures (with location)

List of References

A. FERC Letter Requiring Part 12D Inspection

Note: May include specific FERC concerns to be addressed by Part 12D Independent Consultant.

B. FERC Letter Approving Consultant

Note: Include date of report outline provided by FERC.

C. Project Figures

This Appendix should include the following figures as appropriate. All Figures should be consecutively numbered. Figures should be general without excessive detail so as to be clearly legible. Figures should include documentation of significant changes since last Part 12D report. If STI document to be directly bound in this report, do not duplicate the figures. FERC Exhibit and relicensing drawings can be used.

- Location map with project facilities located including conveyance systems and access routes from main roads and nearest town
- Plans of project facilities
- Typical sections and profiles of key project features (dams, spillways, powerhouses, intakes, emergency/fuse plug spillways, chute profiles, etc.)
- Profiles and typical sections of water conveyance systems (canals, tunnels, penstocks, flumes, surge chambers, etc)
- Satellite or aerial photo of project and downstream area
- Spillway and tailwater rating curves

D. Instrumentation Monitoring Data Plots

Note: Plans and cross-sections with locations of each instrument, including design phreatic surface or uplift pressure profile, and tabulated data for each instrument are included in the "Supporting Technical Information" document only. See Chapter 9, Instrumentation and Monitoring, of the Engineering Guidelines for additional information. Only time versus reading graphs are included here as NEW information.

If data plots are included in Section 4 of the Part 12D report, a statement should be provided here directing the reader to Section 4 for the information.

- Time versus Reading data plots

- Plot all data to date, not just last five years (alternative is to plot last 15 years and note historic range for each unit)
- Do not put too many instruments on one plot
- Try to put all instruments from one section or profile on the same plot
- Mark tip elevation, unscreened length, ground elevation and top of piezometer elevation for each unit on the data plot
- Use symbols for each unit, not just colors (colors do not reproduce in black and white and some people are color blind)
- Include headwater and tailwater levels on each plot
- Force all time scales to show full year cycles from January through December
- For multiple plots for the same project, force vertical and horizontal scales on all plots of the same type to have the same scale or total range so plots can be directly overlaid
- Mark threshold values
- Show monthly precipitation on one sheet
- Mark action levels requiring emergency response

E. Inspection Photographs

F. Inspection Checklist (optional)

G. Operation and Maintenance Documentation (if required)

Appendix I
Guidelines for Supporting Technical Information

Purpose:

The purpose of the Supporting Technical Information document (STI) is to summarize those project elements and details that do not change significantly between quinquennial FERC Part 12D Independent Consultant Safety Inspection Reports. The licensee will create and maintain this document for use by themselves, the Part 12D Consultant and the FERC.

The STI should include sufficient information to understand the design and engineering analyses for the project such as:

- A complete copy of the Potential Failure Mode Analysis report
- A detailed description of the project and project works
- A summary of the construction history of the project
- Summaries of Standard Operating Procedures
- A summary of geologic conditions affecting the project works
- A summary of hydrologic and hydraulic information
- Summaries of instrumentation and surveillance for the project and collected data
- Summaries of stability and stress analyses for the project works
- Pertinent correspondence from the FERC and state dam safety organizations related to dam safety

The STI should use tables, figures, and drawings in preference to text and should not include complete copies of the original documents except for the “Potential Failure Mode Analysis” study report. Only key paragraphs of the original reports should be included in this document for clarity.

The STI is a “living” document, in that as new data or analyses become available they are appended to the initial STI and outdated material is removed. The document should be bound in a three ring binder to facilitate updating the STI as necessary.

The Licensee should coordinate this document with the Part 12D inspection report outline to be sure the Independent Consultant will have all the information necessary for review of the project. The initial STI should be provided to the Independent Consultant and three hard copies and two digital copies shall be submitted to the FERC. Updates to this document shall be provided to the current FERC Part 12D Independent Consultant for review, to the FERC and to other document holders. Document holders should be requested to insert the updated pages in the STI, and add the revision to the revision notice log in the front of the STI.

Except for the initial submittal of an STI document, if no significant changes have been made to the STI since the prior Part 12D Inspection report, either a digital copy of the most current STI in *.pdf, *.jpg, *.tif, or other acceptable formats (check with the FERC for acceptability of alternative formats prior to submittal) or a hard copy of the STI shall be included with the

Part 12D report. For small projects, the STI document may be bound with the Part 12D report.

The complete STI should be reviewed and reprinted at least every 15 years and hard copies submitted with the Part 12D report.

The "Supporting Technical Information" document must include a revision sheet and contain the following sections:

Section	Title
	Table of Contents
1.	**Failure Mode Analysis Study Report**
2.	**Description of Project Structures**
3.	**Construction History**
4.	**Standard Operation Procedures**
5.	**Geology**
6.	**Hydrology / Hydraulics**
7.	**Instrumentation**
8.	**Stability / Stress Analysis of Project Structures**
9.	**Spillway Radial Gates**
10.	**Pertinent Correspondence Related to Safety of Project Works**
11.	**References**

The information to be included in each section is described below.

SUPPORTING TECHNICAL INFORMATION

Revision Log
Table of Contents

1.0 Potential Failure Mode Analysis Study Report

Include a complete copy of the latest "Failure Modes Analysis" study report with all attachments. All updates shall be included in this Section of the STI.

2.0 Description of Project Works and Project Drawings

This is a detailed description of the project and project works that is part of the Part 12D Independent Consultant review. In general, this information will come directly from existing sources such as prior Part 12D Inspection Reports, licensing or relicensing documents or company brochures. The detailed descriptions would include the following elements as appropriate:

2.1 General project description including project name and owner

2.2 Project location including nearest town(s), river system, etc.

2.3 Purpose of Project

2.4 Main dam and any auxiliary dams

2.5 Spillway(s) including stilling basins

2.6 Non-overflow water retaining structures such as powerhouses

2.7 Intakes

2.8 Conveyance systems (penstocks, tunnels, surge chambers, flumes, canals, inverted siphons, including control, regulating, and pressure relief devices, etc.)

2.9 Powerhouse(s)

2.10 Low level outlets including minimum flow devices

The following drawings shall be included

2.11 USGS Quad map or other location map with project facilities located including conveyance system alignment

2.12 Plan of licensed project facilities and project boundaries

2.13 Typical sections and profiles of key project works (dams, spillways, powerhouses, intakes, canals, tunnels, penstocks, flumes, surge chambers, inverted siphons, etc.)

2.14 Satellite or aerial photo of project and downstream area if available

3.0 Construction History

In general, this information will be copied directly from existing sources such as prior Part 12D reports, construction reports or company brochures. Include a summary of the project construction history based on the following sources of information:

3.1 Design reports and pertinent memoranda from licensing and permitting documents

3.2 Laboratory investigations and construction testing reports

3.3 Field and lab geotechnical investigations

3.4 Construction reports and photographs

3.5 Specification documents

3.6 Reports of major modifications conducted for dam safety since last Part 12D inspection

3.7 Construction chronology that includes all a summary of original construction and all significant work completed related to project safety. Do not include routine maintenance items such as gate painting, unit overhauls, etc.

4.0 Standard Operation Procedures

Include a statement summarizing the standard operating procedures for the project. This section should include seasonal minimum flow requirements, lead and follow gate sequence, reservoir level restrictions by season, etc.

5.0 Geology and Seismicity

In general, this section should be copied from existing reports and company brochures. Include summaries of applicable information in the following sections:

5.1 Geology

5.1.1 Regional geology

5.1.2 Site geology and local foundation conditions including geologic maps, cross-sections and profiles under the dam(s) and pertinent project works.

5.1.3 Potential landslides, loose rock formations or adverse bedding orientations that could affect project works

5.1.4 Potential sinkhole, karst, solutioning, basalt flow issues, etc. that could impact project works

5.1.5 Potential weak seams such as bentonite or soluble gypsum layers

5.1.6 Geologic artesian sources (geothermal, high abutments, etc.). Do not include artesian pressures due to normal dam seepage.

5.2 Seismicity

- 5.2.1 Map of fault traces that effect project
- 5.2.2 Table of fault, distances, depths, magnitude at fault, PGA at site, etc.
- 5.2.3 Site MCE and DBE development
- 5.2.4 Time history of adopted earthquakes
- 5.2.5 Floating earthquake magnitude, PGA, and distance
- 5.2.6 Historic earthquake centers map

The USGS website (http://neic.usgs.gov) includes information on seismicity and may be a useful reference.

6.0 Hydrology and Hydraulics

Provide supporting information to document the development of the Probable Maximum Flood (PMF) and the routing of the PMF through the reservoir and project spillways. In general, this information will come directly from existing sources such as prior Part 12D inspection reports or company reports. The following information that should be included as applicable:

6.1 Hydrology

- 6.1.1 Hydrometeorology report used
- 6.1.2 Probable Maximum Precipitation for general and local storms
- 6.1.3 Drainage basin description including drainage area
- 6.1.4 Antecedent conditions
- 6.1.5 Loss rates
- 6.1.6 Basin and sub-basin precipitation/runoff models
- 6.1.7 Unit Hydrograph
- 6.1.8 Reservoir inflow and outflow hydrographs for the PMF event
- 6.1.9 Floods of record including highest flood flows and reservoir elevations

6.2 Hydraulics – Dams

- 6.2.1 Project discharge-rating curves (For multiple gate spillways, outlet structures, powerhouse units, and emergency/fuse plug spillways, include the contribution of each component as well as the total capacity. Include the equations used to develop the curves including overtopping and orifice flow where appropriate).
- 6.2.2 Tailwater rating curve (Compare to dam break studies)
- 6.2.3 Normal and flood freeboard without wave action
- 6.2.4 Zero freeboard flood capacity (without wave allowance)
- 6.2.5 Inflow Design Flood (based on dam break)
- 6.2.6 Reservoir Probable Maximum and Inflow Design Flood outflow hydrographs and corresponding reservoir levels
- 6.2.7 Freeboard for general and thunderstorm events

6.2.8 Stilling basin or plunge pool design flood flow

6.2.9 Operating rule curve (if storage reservoir)

6.3 Hydraulics – Water Conveyance Systems

6.3.1 Hydraulic capacity of water conveyance system(s)

6.3.2 Normal operating freeboard

6.3.3 Spillway discharge rating curve(s)

6.3.4 Summary of transient analysis

7.0 Instrumentation

This section is to include drawings and/or sketches showing the location of each active instrument. Include cross-sections of project structures showing instrument tip elevation, ground elevation and readout point location. See Chapter 9, Instrumentation and Monitoring, of the engineering guidelines for additional discussion.

Note: time versus reading graphs for each instrument will be included only in the Part 12D inspection report.

7.1 Plans, sections, and details of active or useful reference instrumentation

If a unit has been abandoned or replaced, but the historic data is still being used for safety evaluations, include the appropriate information for the record

7.2 Reading frequency for each instrument (reading procedures should not be included in this document)

7.3 Procedures for resolving spurious readings

7.4 Tabulated Data for each instrument

7.5 Type of instrument (pneumatic/vibrating wire piezometer, Parshall flume, gape gage, inclinometer, etc)

7.6 Predicted value for each instrument (threshold values are values used in design or analysis of project structures)

7.7 Historic range of readings for each instrument

7.8 Threshold and Action level for each instrument

8.0 Stability and Stress Analyses of Project Structures

Because every dam and hydroelectric project is unique, it is not possible to list here all the various items that are required to adequately detail stability or stress assessments of the project water retaining structures. It will be the responsibility of the Licensee to include all information necessary for the reader to understand the assumptions, methods of analysis, and load cases assessed for each project structure. Stability and stress analyses for each structure shall be summarized graphically for ease of understanding and communication and to create a permanent record storage.

The following types of information should be provided:

8.1 General

8.1.1 Listing of credible load cases analyzed (including water levels for dam, canal and flume analyses or pressure for penstock and flowline analyses)

8.1.2 Statement of the method of analysis used and the computer program adopted.

8.1.3 Properties of materials based on site specific tests or assumptions (state which). Include representative test data and summary sheets.

8.2 For each gravity structure and load case:

8.2.1 Graphic free body diagram (cross-section) of each structure showing:

- the assumed self weight of the cross section
- all applicable loads including, as appropriate:
- assumed uplift pressure distribution
- silt loads
- headwater and tailwater loads
- point loads
- ice load

8.2.2 Key elevations

8.2.3 Key lateral dimensions

8.2.4 Piezometer and drain locations

8.2.5 Foundation shear strength parameters

8.2.6 Minimum cohesion to meet stability criteria

8.2.7 Negative crest pressures

8.2.8 Concrete unconfined and splitting tensile strength test results

8.2.9 AAR potential or evidence, failure planes investigated, etc.

8.3 For each embankment structure and load case:

8.3.1 Graphic cross-section showing

- embankment zoning
- phreatic surface
- critical failure surfaces
- key elevations
- key lateral dimensions
- slopes
- headwater and tailwater elevations

8.3.2 Potential for uncontrolled seepage at toe

8.3.3 Summary of liquefaction analyses

8.3.4 Summary of deformation analyses

8.3.5 Procedures used to determine soil properties, etc.

- Soil Classification
- Atterberg limits
- etc.

8.3.6 Procedures used to determine soil strengths

- Triaxial Tests (type and loadings)
- Standard Penetration Tests
- Cone Penetration Tests
- Becker Hammer Tests
- etc.

8.4 For each arch dam load case:

8.4.1 Finite element mesh

8.4.2 Stress contours

8.4.3 Vector diagrams

8.4.4 Thrust block stability and joint sterionets

8.4.5 Pulsating load potential, etc.

8.5 For each water conveyance system that has a highlighted PFM

8.5.1 Stress and stability analyses

8.6 Summary table of factors of safety for each structure and load case, with required value.

For embankment structures and overburden foundations, the material strengths used in the stability analyses should be properly identified i.e. effective stress or total stress. The methods used to determine pore pressures should also be described.

For gravity structures, it is useful to provide a spreadsheet of the key numbers from the analysis.

9.0 Spillway Gates

For each spillway gate type, include the following information:

9.1 Table of material properties (steel type, trunnion bearing type and friction properties, etc).

9.2 A summary of the stress analysis computations

9.2.1 Graphic of gate model used for stress analysis

9.2.2 Table of critical stresses in each member for each load condition.

9.3 Trunnion, wheel, or other lubrication procedures, schedule, etc.

9.4 Summary of gate hoist motor load tests to date (line-line voltage, amperage draw, reservoir level, and initial draw if available)

9.5 Spillway gate detailed inspection report

10.0 Pertinent Correspondence Related to Safety of Project Works

Include FERC annual operation inspection reports for the five years preceding the current Part 12D inspection report. Include any major correspondence from FERC or State Dam Safety Agencies related to outstanding dam safety issues for the project.

11.0 References

List of references available for review of dam safety issues and that were used to assemble this document.

Attachments

1) Example of Detail Expected in Supporting Technical Information Document
2) Example of Summary of Embankment Stability Analysis
3) Example of Summary of Structural Stability Analysis
4) Example of Summary of Hydrologic and Hydraulic Information
5) Example of Summary of Instrumentation and Surveillance Information
6) Example of Document Control Log Sheets

Attachment 1

Example of Detail Expected
in
Supporting Technical Information Document

BASIC DATA AND ANALYSES

Spillway Adequacy

A. Previous Studies

The original design flood study for Big Hole Dam was presented in "A Study of the Maximum Probable Floods for the Middle Fork of the Big River Project", dated October 1961 and revised in August 1962 by ABC. The design flood developed by that flood study, when routed through the reservoir and spillway, resulted in a peak discharge of 58,800 cfs at reservoir water surface Elevation 4,643.2, leaving a freeboard of 6.8 feet to the nominal dam crest.

In February 1965, ABC updated the flood study by deriving a probable maximum flood based on U.S. Weather Service Hydrometeorological Report No. 36 and U.S. Corps of Engineers reductions. This 1965 study resulted in a maximum water surface Elevation 4,646.7, leaving a freeboard of 3.3 feet to the nominal dam crest elevation.

In 1973, T. J. Corwin reviewed the flood studies, made some independent evaluations, and concluded that the maximum inflow flood would be 66,000 cfs. When routed through the reservoir and spillway, the peak discharge would be 55,000 cfs with a maximum reservoir water surface Elevation 4,644, leaving 6.0 feet of freeboard.

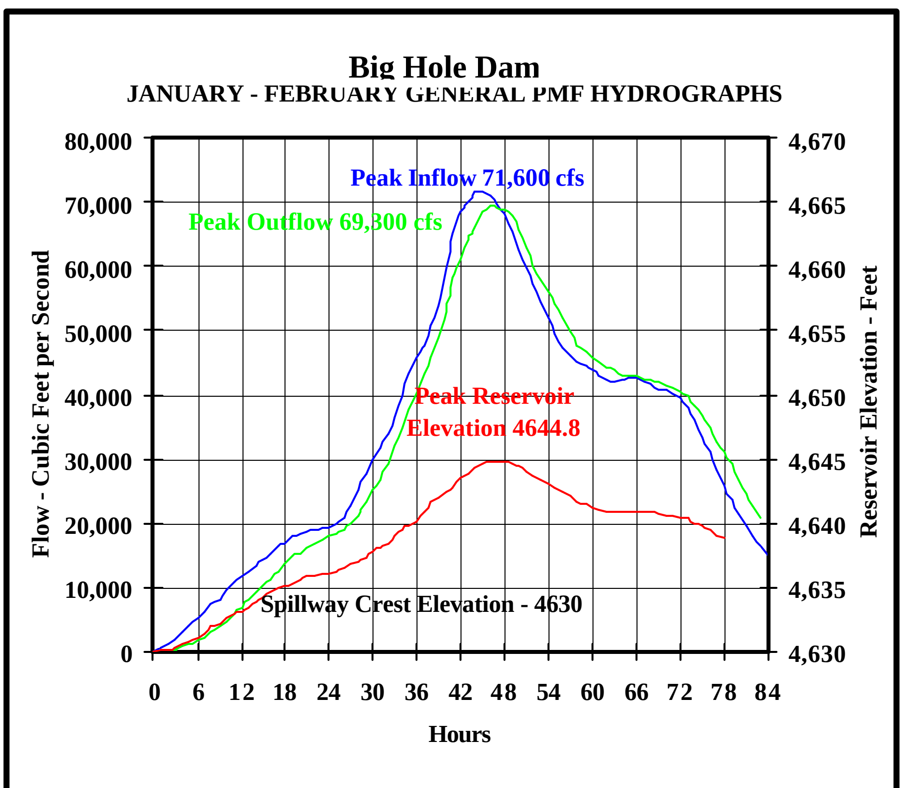


Figure 1

B. Methodology to Determine PMF

In 1982, FERC directed Big County Water Agency to provide additional information on flood hydrology for the Middle Fork American River Project. The Agency retained Hydrotech of Bigville to perform that study. Hydrotech's report "Probable Maximum Flood Study for Big Hole, Interbay, and Little Hole Afterbay Dams", dated October 1982, was reviewed and excerpts presented as part of the 1986 Five Year Dam Safety Inspection report. Excerpts from that report describing the methodology used to determine the PMF for Big Hole Dam follow.

“The probable maximum floods

are based upon a probable maximum storm that could occur during January or February. The storm is estimated using procedures presented in Hydro-meteorological Report No. 36, entitled "Interim Report, Probable maximum Precipitation in California", which was originally issued in October 1961, and was revised in October 1969."

"The probable maximum storm was distributed into hourly precipitatio0n amounts, hourly melting of snowpack was calculated using probable maximum storm temperature and winds, immediate surface runoff losses were subtracted from the hourly precipitation and snowmelt, and the remaining excess amounts of precipitation and snowmelt along with spill from any upstream reservoirs were routed through the basin stream channels to the basin discharge point…"

The Hydrotech report is organized into three sections describing the basin characteristics, the flood analysis, and the probable maximum flood calculation. The Clark Unit Graph method (C. O. Clark, "Storage and the Unit Graph" ASCE Transactions, 1945.)

"Probable maximum flood inflows to Big Hole Reservoir … have been calculated using estimated probable maximum precipitation, snowmelt associated with the probable maximum storm, applying losses based upon losses during historic storms, and routing the sub-basin runoff to the appropriate reservoir." "Each reservoir was assumed to be full at the start of the probable maximum flood."

The flood routing from the Hydrotech study is presented on Figure 1. Peak flood inflow was found to be 71,600 cfs and peak outflow was 69,300 cfs at a maximum reservoir stage of 4,644.8.

It is considered that the Hydrotech flood study was carried out in accordance with previously appropriate standards and procedures. However, in May 1996 and January 1997, large rainfall floods occurred which could affect the unit hydrographs and loss rates used to develop the probable maximum flood (PMF) from the probable maximum precipitation (PMP). In 1999, the National Oceanic and Atmospheric Administration and the Army Corps of Engineers issued Hydrometeorological Report (HMR) No.

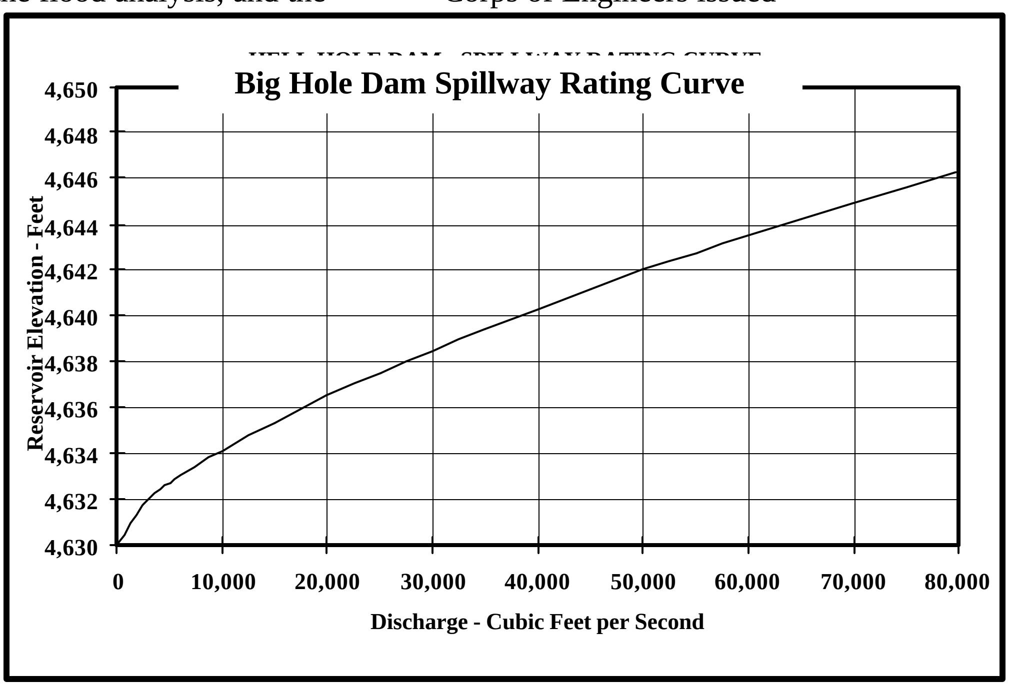


Figure 2

59, which superseded HMR No. 36 on which the precipitation developed in the Hydrotech 1982 study was based. While the precipitation, loss rates and unit hydrographs used in the Hydrotech study were appropriate and conservative for that time, the precipitation is no longer current data and the loss rates and unit hydrographs should be reviewed as a result of the 1996 and 1997 storms.

The maximum reservoir stage for the routed flood left 5.2 feet of freeboard to the nominal dam crest elevation. That freeboard is judged to be adequate for a dam the height, configuration and material of Big Hole Dam but a new flood study must be prepared for Big Hole Dam and the freeboard adequacy must be reviewed when the results of that study are available.

C. Spillway Rating Curve

The spillway rating curve from the Hydrotech 1982 report is presented on Figure 2. That rating curve has again been reviewed and found to be conservative and appropriate for the spillway at Big Hole Dam.

Structural Stability

A. Previous Studies

The original design analysis was carried out by AB Engineers (ABE) as reported in their 1982 Engineering Data Report. Harlan Miller Tait Associates (HMTA) updated the Stability Analysis for the dam as a supplement, dated April 4, 1984, to the fourth Five Year Dam Safety Inspection Report. In the fifth Five Year Dam Safety Inspection Report (HMTA, 1986), the stability analysis was again updated using additional seismicity data and a more complete analysis.

To comply with FERC criteria, a Simplified Displacement Analysis (SDA) was performed as part of the 1991 Five Year Dam Safety Inspection by HTA. Data and analysis descriptions from those HTA reports are summarized in this Appendix.

B. Method of Analysis

1. Static Analysis

To analyze the static loading conditions, the static stability analysis computer program TSLOPE (by TAGA Engineering Software Services of San Ramon, California) was used.

The Spencer's method program option was selected to determine the factor of safety of a slope using noncircular failure surfaces selected by the investigator. The sliding mass is divided into slices, and all interslice side forces are parallel to each other. Spencer's method satisfies equilibrium conditions for overall moment, individual slice moment, and vertical and horizontal forces.

2. Earthquake Deformation Analysis

For the earthquake deformation analysis, a simplified displacement analysis (SDA) was carried out. The controlling causative fault for the Big Hole Dam site is the undefined “local earthquake” that is capable of an MCE of M=5 at a distance of 5 km that could result in a peak ground acceleration (PGA) at Big Hole Dam of up to 0.19g (Section IV, E. Seismicity) (Sadigh, et.al., 1997). A conservative seismicity of 0.2g was used in the 1991 analysis.

The SDA was performed in three steps:

1. A yield acceleration was determined using static analysis for failure surfaces that would intersect the crest and adversely affect the freeboard.

2. A time-history of accelerations in the dam caused by the controlling earthquake was calculated for the selected yield acceleration surface.

3. The time-history accelerations that exceeded the yield acceleration were used to estimate incremental displacements, which were averaged to calculate the permanent displacement along the failure surface.

TSLOPE was used to determine the yield acceleration for the selected failure surfaces. The yield acceleration is defined as the pseudostatic seismic coefficient necessary to reduce the static factor of safety for the selected failure surface to 1.0, the point of incipient static failure. The Spencer's method program option was selected to determine the factor of safety of a slope using failure surfaces selected by the investigator, as described under Static Analysis, above. Various failure surfaces, which were selected to intersect the crest of the dam and to adversely affect the freeboard, were tried until several surfaces with lower yield accelerations were found.

The program SHAKE, developed at the University of California at Berkeley by Per Schnabel, John Lysmer, and H. Bolton Seed, was used to model the dam's dynamic response to site-modified earthquake records and to estimate the time-history of acceleration on the selected yield acceleration surfaces. SHAKE is used to compute the dynamic response of a one-dimensional system of infinitely long, homogenous, visco-elastic layers subjected to vertically traveling shear waves. The program is based on the continuous solution to the wave-equation (Kanai, 1951) adapted for use with transient motions through the use of the Fast Fourier Transform Algorithm (Cooley and Tukey, 1965). The input to the program is discrete, consisting of acceleration values spaced at a constant time interval. The maximum absolute acceleration value and the time interval between the acceleration values are varied so that the acceleration and predominant period of the record matches those expected at the site. The earthquake records chosen to model the site were the 1954 Taft earthquake and a synthetic motion created by H. B. Seed and I. M. Idriss, both scaled to a PGA of 0.20g. The output from SHAKE is also in discrete format, consisting of acceleration values at constant time intervals that represent the acceleration time-history curve of points within the soil profile chosen by the investigator.

The dynamic response of the dam embankment due to an earthquake with a PGA of 0.20g was computed on the maximum section at several vertical locations in profiles located near the axis of the dam, near mid-slope, and near the embankment toe (see Figures D-3 and D-4) using the program SHAKE. In a trial and error process, the material stiffness parameters were softened at the failure surface until the average acceleration above the failure surface was approximately equal to the yield acceleration. This procedure was required to keep the system in static equilibrium. The acceleration time history at the failure surfaces at the various profiles was then computed, and the maximum value is presented on the Figures. Typically, the Taft motion produced greater accelerations at the failure surfaces.

The program DISPLMT, developed at Arizona State University by William

Houston and Sandra Houston, was used to compute expected permanent displacements in the dam embankment using the acceleration time-history on the selected yield failure surfaces. The program estimates permanent displacements by double integrating accelerations above the yield acceleration produced at the failure surface. The program utilizes the Newmark numerical method to perform the integration, determining the area under the portion of the acceleration time-history curve that exceeds the minimum yield acceleration.

The DISPLMT program calculates the movements along the failure surface using the acceleration time-history generated by SHAKE as the response or input motion. The yield acceleration is assumed constant with respect to time and displacement. The calculated displacement varies from the near-axis, middle, and toe profiles of the embankment slope.

C. Material Properties

ABE data (1962 and 1968) indicate that the foundation was to be on unweathered rock. As-built drawings show the foundation to be hard, massive granitic rock. For the purpose of the stability analysis, it is considered that the foundation is substantially stronger than the embankment.

Materials obtained from the borrow areas and used in the core of the embankment were tested by ABE for their strength characteristics. These tests are summarized in their report (ABE, 1962), and the design parameters adopted are given below. The material strength parameters discussed in that report were judged conservative and appropriate; therefore, those same parameters were used in the 1986 and 1991 analysis and are as follows:

Material Properties Used in Analyses

Parameter	Zone 1	Zone 2 - 7
Moist Unit Weight, γ_m (pcf)	127	124
Saturated Unit Weight, γs (pcf)	130	140.4
Friction Angle, Ø (degrees)	33	40
Cohesion, c (psf)	200	0

D. Phreatic Surface Assumptions and Seepage Pressure Distribution

The phreatic surfaces and hydrostatic forces are based on the water levels shown on the stability analysis drawings (Figures D-3 and D-4). Uniform head loss was used through the core, and it was considered that the transition, drain material, and rockfill are free draining with no head loss in the upstream rockfill and transition. In 1984, FERC questioned the assumption that the upstream rockfill would be free-draining with respect to rapid drawdown stability conditions. An analysis of the permeability of the upstream shell with respect to maximum rate of rapid drawdown was made and presented in the 1986 Five Year Dam Safety Inspection report. The assumption that the upstream rockfill was free-draining with respect to rapid drawdown was affirmed.

E. Stability Conditions, Minimum Criteria, and Calculated Factors of Safety

The stability conditions, minimum criteria, and the calculated factors of safety are presented in the following table. The minimum criteria factors of safety are from: “Engineering and Design Stability of Earth and Rockfill Dams,” EM1110-2-1902, by the Corps of Engineers, April 1, 1970.

For the earthquake deformation analysis, the criterion adopted is that the displacement must not be great enough to lower the crest of the dam below the maximum normal storage elevation in the case of occurrence of the MCE.

Stability analyses were performed for the maximum dam section with the crest at elevation 4660 to allow for the original camber. Pool elevations used in the analysis are elevation 4640, 10 feet above normal maximum operating level, PMF pool elevation 4646, and partial pool elevations 4340, 4465, and 4565.

Analyses were performed for full suites of possible failure surfaces for each of the loading conditions listed above. For each static loading case, we found a surface with a lowest factor of safety and bounded above and below with more stable slip surfaces. To determine the yield accelerations for the earthquake deformation analysis, the same procedure was used. Earthquake time-histories and displacement analyses were performed on only the most critical surfaces (based on the results of the yield acceleration analyses) that, based on their location relative to the crest, adversely affect the freeboard of the dam.

F. Summary of Results - Embankment

The detailed results of the analyses were presented on Figures VII-1 and VII-2 in the HTA 1991 report, and those figures are reproduced as Figures D-3 and D-4 in this Appendix. A Summary of the results is presented in the table following.

An SDA was performed on the downstream failure surface with the lowest yield acceleration (Figure D-3, Case 3, Surface G). The maximum expected displacement was calculated to be 0.01 feet.

On the upstream slope, the failure surface with the lowest yield acceleration (Figure D-4, Case 8, Surface E) was judged to not adversely affect the freeboard of the dam if displacement occurred. Therefore, an SDA was performed on the failure surface with next lowest yield acceleration, Surface D with water at Elevation 4465. The maximum expected displacement was calculated to be 0.01 feet.

The results of these stability and displacement analyses were reviewed as part of this (2001) Inspection. The results indicate that the dam has satisfactory factors of safety for all static loading conditions and that the deformations under earthquake loading are expected to be small and will not reduce the freeboard. The seismicity used for the displacement analysis is judged to be conservative and appropriate.

References

Cooley, J. W., and Tukey, J. W., 1965, "An Algorithm for the Machine Calculation of Complex Fourier Series," Mathematics of Computation, Vol. 19, No. 90, pp. 297-301.

Harlan Miller Tait Associates, 1984, Stability Investigation, Big Hole Dam.

Harlan Miller Tait Associates, 1986, Five-Year Dam Safety Inspection Report, Big Hole Dam.

Harlan Tait Associates, 1991, Five-Year Dam Safety Inspection Report, Big Hole Dam.

McCreary Koretsky Engineers, 1962, "Big Hole Dam Engineering Data," dated March, 1962.

McCreary Koretsky Engineers, 1968, "Placer County Water Agency, Middle Fork American River Project, Big Hole Dam, Sections and Details," dated January, 1968.

Sadigh, K.;Chang; Egan; Makdisi; Youngs (Geomatrix) *Attenuation Relationships for Shallow Crustal Earthquakes Based on California Strong Motion Data.* Seismological Research Letters, Volume 68, Number 1; January/February 1997, Seismological Society of America

Case	Slope/Condition	Min. Criteria F.S.	Min. Computed F.S.
1	Downstream - Pool Elev. 4640, 10 feet above Normal Maximum Operating level	1.5	1.47
2	Downstream/PMF Pool Elev. 4646	1.4	1.47
3	Downstream - Pool Elev. 4640 with Seismic	N. A.	Displacement 0.01 ft. Yield Accel. 0.22
4	Upstream - Pool Elev. 4640	1.5	2.33
5	Upstream - PMF Pool Elev. 4646	1.5	2.34
6	Upstream Pool Elev. 4640 with Seismic	N.A.	Max. Displacement 0.01 ft.- Minimum Yield Accel. 0.30
7	Upstream: Pool Elev. 4340 Pool Elev. 4465 Pool Elev. 4565	1.5	1.98 1.88 2.10
8	Upstream w/ Seismic: Pool El. 4340 Pool Elev. 4465 Pool Elev. 4565	N. A.	Min. Yield Accel's.0.34 0.25 0.24
9*	Upstream/Rapid Drawdown from Normal Maximum Operating Pool to Elev. 4340	1.2	1.95

*Results of Analysis taken from 1986 Five Year Dam Safety Inspection Report (HMTA, 1986).

Attachment 2

Example of Summary
of
Embankment Stability Analysis

TABLE 5.2.1 - MATERIAL PROPERTIES
Stability Analysis of Embankments
SAMPLE Project

Material Description	Y_{sat} (pcf)	Y_{dry} (pcf)	F ' (deg.)	c' (tsf)
Lower Reservoir				
Random Fill	147	135	40	0
Compacted Rockfill	144	130	45	0
Filter	141	125	35	0
Clay Core	134	113	25	0
Silt Core	140	—	35	0
Sand/Gravel Foundation	141	125	35	0
Red Silt Foundation	140	—	40	0
Berm Fill	132	110	30	0
Upper Reservoir Dike				
Random Fill	147	135	40	0
Core/Random Fill	147	135	40	0
Filter	141	125	35	0
Sand/Gravel Foundation	141	125	35	0

Y_{sat} = saturated (total) unit weight (pcf)
Y_{dry} = dry unit weight (pcf)
Φ' = effective stress friction angle (degrees)
c' = effective stress cohesion intercept (tsf)

TABLE 5.2.3 - FACTORS OF SAFETY
Lower Reservoir Sta. 12+00
Sample Project

LOWER RESERVOIR DAM EMBANKMENT[1] STA.12+00						
Load Case	Description	Reservoir Elevation (feet)	Factor of Safety			
			Downstream Slope		Upstream Slope	
			Calc.	Req'd	Calc.	Req'd
I	Normal maximum pool with steady seepage	900.5	1.74 2.44[2]	1.5	1.95 2.13[2]	1.5
II	Flood surcharge (PMF)	908.5	1.66	1.4	N/A	N/A
III	Rapid drawdown	860.0	N/A	N/A	1.51	1.1
IVa	Normal maximum pool w/earthquake[3]	900.5	1.25	1.0	N/A	N/A
IVb	Rapid drawdown w/earthquake[3]	860.0	N/A	N/A	1.03	1.0

1. From: Second Safety Inspection Report, Supplement 2, dated February 1988.
2. Based on infinite slope.
3. Pseudo-static earthquake coefficient, a_h = 0.10g.

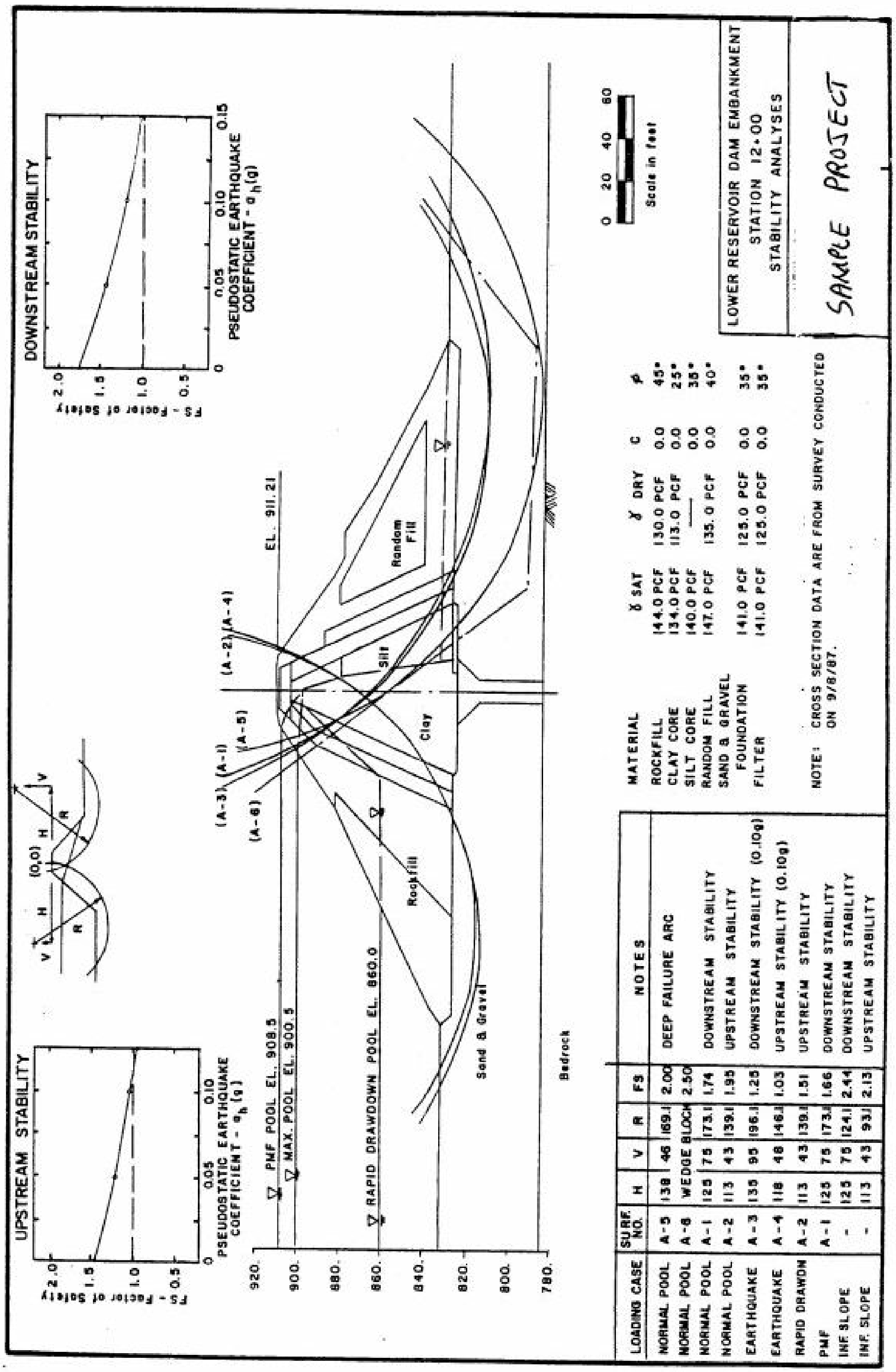
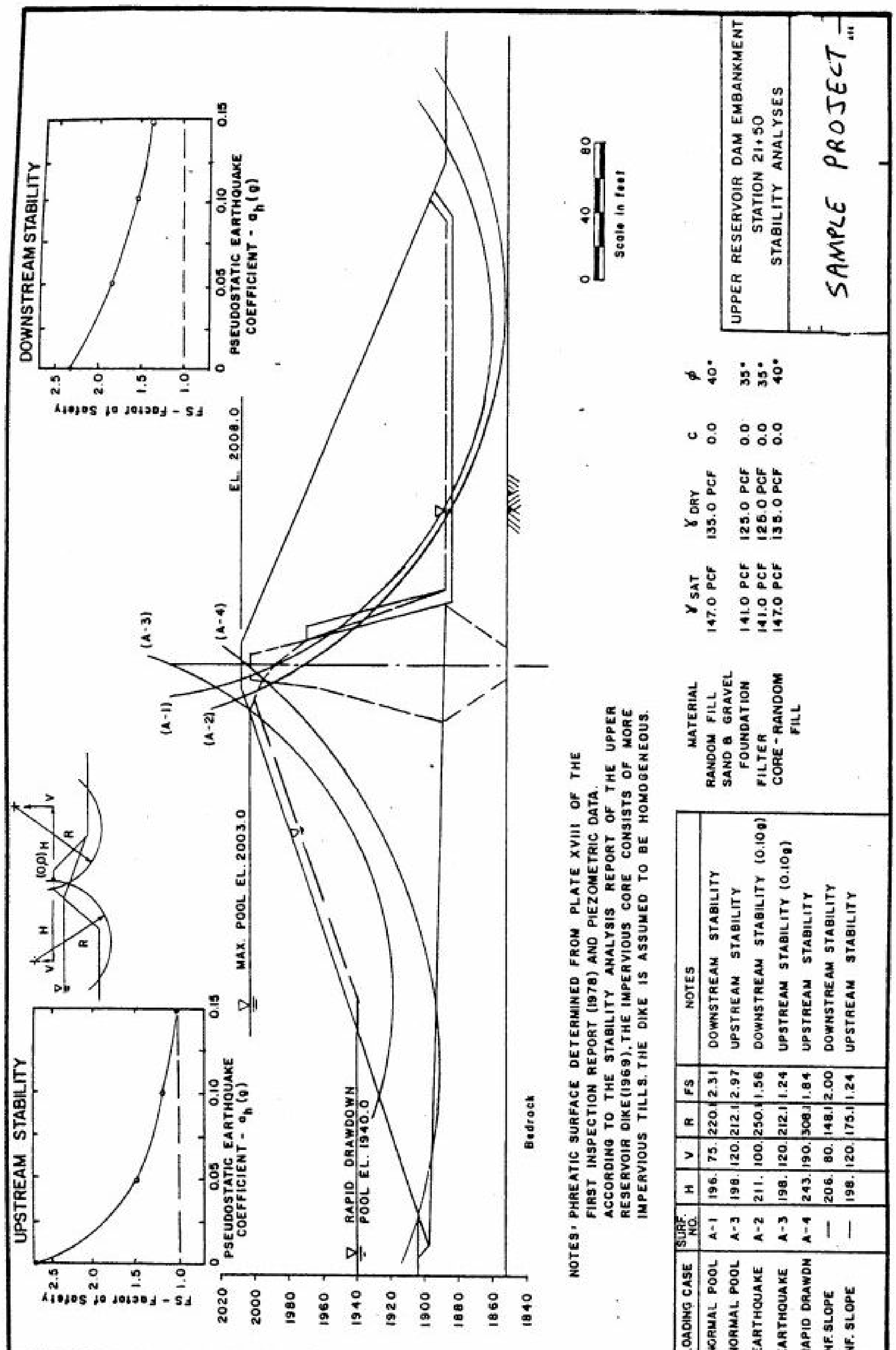

UPSTREAM STABILITY
FS - Factor of Safety
PSEUDOSTATIC EARTHQUAKE COEFFICIENT - a_h (g)
DOWNSTREAM STABILITY
FS - Factor of Safety
PSEUDOSTATIC EARTHQUAKE COEFFICIENT - a_h(g)
(0,0)
PMF POOL EL. 908.5
MAX. POOL EL. 900.5
RAPID DRAWDOWN POOL EL. 860.0
EL. 911.21
(A-3) (A-1) (A-5) (A-6) (A-2) (A-4)
Rockfill
Clay
Silt
Random Fill
Sand & Gravel
Bedrock
LOADING CASE | SURF. NO. | H | V | R | FS | NOTES
NORMAL POOL | A-5 | 138 | 46 | 169.1 | 2.00 | DEEP FAILURE ARC
NORMAL POOL | A-6 | WEDGE BLOCK | 2.50
NORMAL POOL | A-1 | 125 | 75 | 173.1 | 1.74 | DOWNSTREAM STABILITY
NORMAL POOL | A-2 | 113 | 43 | 139.1 | 1.95 | UPSTREAM STABILITY
EARTHQUAKE | A-3 | 135 | 95 | 196.1 | 1.25 | DOWNSTREAM STABILITY (0.10g)
EARTHQUAKE | A-4 | 118 | 48 | 146.1 | 1.03 | UPSTREAM STABILITY (0.10g)
RAPID DRAWDN | A-2 | 113 | 43 | 139.1 | 1.51 | UPSTREAM STABILITY
PMF | A-1 | 125 | 75 | 173.1 | 1.66 | DOWNSTREAM STABILITY
INF. SLOPE | - | 125 | 75 | 124.1 | 2.44 | DOWNSTREAM STABILITY
INF. SLOPE | - | 113 | 43 | 93.1 | 2.13 | UPSTREAM STABILITY
MATERIAL | γ SAT | γ DRY | C | φ
ROCKFILL | 144.0 PCF | 130.0 PCF | 0.0 | 45°
CLAY CORE | 134.0 PCF | 113.0 PCF | 0.0 | 25°
SILT CORE | 140.0 PCF | —— | 0.0 | 35°
RANDOM FILL | 147.0 PCF | 135.0 PCF | 0.0 | 40°
SAND & GRAVEL FOUNDATION | 141.0 PCF | 125.0 PCF | 0.0 | 35°
FILTER | 141.0 PCF | 125.0 PCF | 0.0 | 35°
NOTE: CROSS SECTION DATA ARE FROM SURVEY CONDUCTED ON 9/8/87.
Scale in feet
LOWER RESERVOIR DAM EMBANKMENT
STATION 12+00
STABILITY ANALYSES
SAMPLE PROJECT

FIGURE D.5.2.1

TABLE D.5.2.4 - Factors of Safety
Upper Reservoir Sta. 21 + 50
Sample Project

UPPER RESERVOIR DIKE[1] STA. 21+50						
Load Case	Description	Reservoir Elevation (feet)	Factor of Safety			
			Downstream Slope		Upstream Slope	
			Calc.	Req'd	Calc.	Req'd
I	Normal maximum pool with steady seepage	2003	2.31 2.00[2]	1.5	2.97 1.24[2]	1.5
III	Rapid drawdown	1940	N/A	N/A	1.84	1.1
IIIa	Normal maximum pool w/earthquake[3]	2003	1.56	1.0	N/A	N/A
IIIb	Rapid drawdown w/earthquake[3]	1940	N/A	N/A	1.24	1.0

1. From: Second Safety Inspection Report, Supplement 2, dated February 1988.
2. Based on infinite slope.
3. Pseudo-static earthquake coefficient, $a_h = 0.10g$.



LOADING CASE	SURF. NO.	H	V	R	FS	NOTES
NORMAL POOL	A-1	196.	75.	220.1	2.31	DOWNSTREAM STABILITY
NORMAL POOL	A-3	198.	120.	212.1	2.97	UPSTREAM STABILITY
EARTHQUAKE	A-2	211.	100.	250.1	1.56	DOWNSTREAM STABILITY (0.10g)
EARTHQUAKE	A-3	198.	120.	212.1	1.24	UPSTREAM STABILITY (0.10g)
RAPID DRAWDN	A-4	243.	190.	308.1	1.84	UPSTREAM STABILITY
INF. SLOPE	—	206.	80.	148.1	2.00	DOWNSTREAM STABILITY
INF. SLOPE	—	198.	120.	175.1	1.24	UPSTREAM STABILITY

MATERIAL	γ_{SAT}	γ_{DRY}	c	ϕ
RANDOM FILL	147.0 PCF	135.0 PCF	0.0	40°
SAND & GRAVEL FOUNDATION	141.0 PCF	125.0 PCF	0.0	35°
FILTER	141.0 PCF	125.0 PCF	0.0	35°
CORE - RANDOM FILL	147.0 PCF	135.0 PCF	0.0	40°

FIGURE D.5.2.3

Attachment 3

Example of Summary
of
Structural Stability Analysis

VALUES AND ASSUMPTIONS
STABILITY ANALYSIS
CONCRETE SECTIONS

1. Nomenclature:

   Effective Length = Uncracked Portion of Base

   ΣF_H = Summation of Horizontal Forces - Kips

   ΣF_V = Summation of Vertical Forces - Kips

   ΣM_R = Summation of Resisting Moments - Kip-Ft.

   ΣM_O = Summation of Overturning Moments - Kip-Ft.

   $\frac{M_R}{M_O}$ = Factor of Safety Against Overturning

   $\frac{F_H}{F_V}$ = Coefficient of Sliding

2. Unit Weight of Concrete: 150 lbs./cu. ft.

3. Unit Weight of Water: 62.4 lbs./cu. ft.

4. Uplift Pressure:

   The base pressure was assumed to vary linearly from full head-water pressure at the upstream side to full tailwater pressure at the downstream side taken over 100% of the base area for each case analyzed.

   For analyses which included a reduction in uplift due to foundation drainage, the drains were assumed 50% effective.

   Uplift pressure at drain = TW = 0.5(HW - TW), where HW and TO are the headwater and tailwater pressures, respectively.

   Full headwater pressure over 100% of the area was assumed to extend into the concrete bedrock contact during any case where an assumed crack formed due to the existence of tension stresses in the section foundation. The pressure was assumed to vary linearly from full headwater pressure at the upstream end of the uncracked effective base length to full downstream tailwater pressure at the downstream face.

   Due to the transient or short-term nature of earthquake loading, the uplift is not changed from the pre-earthquake condition due to further propagation of a tensile crack.

   In the event of a tensile crack extending from the heel to the drain', the foundation drains were assumed of greater capacity than the crack. This will result in an uplift pressure distribution equal to that without the crack (full headwater at heel and TW + 0.5(HW-TW) at drain).

5. Lateral Water Pressure:

   Headwater pressures were computed using the full heights of water to headwater elevations over the projected height of the structures. Tailwater pressures were computed using full heights of water Co tailwater elevations for nonoverflow sections and at 60% of full value for cases where deep flow occurs over the ogee spillway, in accordance with U.S. Army Corps of Engineers EM 1110-2-2200 "Gravity Dam Design."

   Tailwater pressures were computed at 100% full value when deep flow occurs over the ogee spillway such that the structure becomes completely submerged, in accordance with data from U.S. Bureau of Reclamation presented in Open Channel Hydraulics by Chow, Ven Te (1959). Figures 14-17 and 14-18.

6. Ice Load:
   5 kips per linear foot at normal water level. If the normal water level is maintained by pin flashboards, water level and ice load are assumed to be at the top of the concrete ogee.

7. Earthquake:

   An acceleration of 0.10 g was applied in a horizontal direction.

   The hydrodynamic force was determined using a method presented in Design of Small Dams, USBR, pages 336-338.

8. Resistance to Sliding:

   Where the ratio of FH/FV is greater than 0.75, the shearing resistance of the foundation to horizontal movement must be investigated using the Shear Friction Formula. The factor of safety against sliding is determined by the Shear Friction Formula as:

$$S_{g\text{-}f} = \frac{f\ V\ +\ C\ A}{H}$$

   where:

   f = Coefficient of the angle of internal friction of foundation material (Tan $\Phi = 0.75$)

   ΣV = Summation of vertical forces

   c = Unit shearing strength at zero normal load on foundation material (0.192 ksi)

   A = Area of potential failure plane (area of base in compression)

   ΣH = Summation of horizontal forces

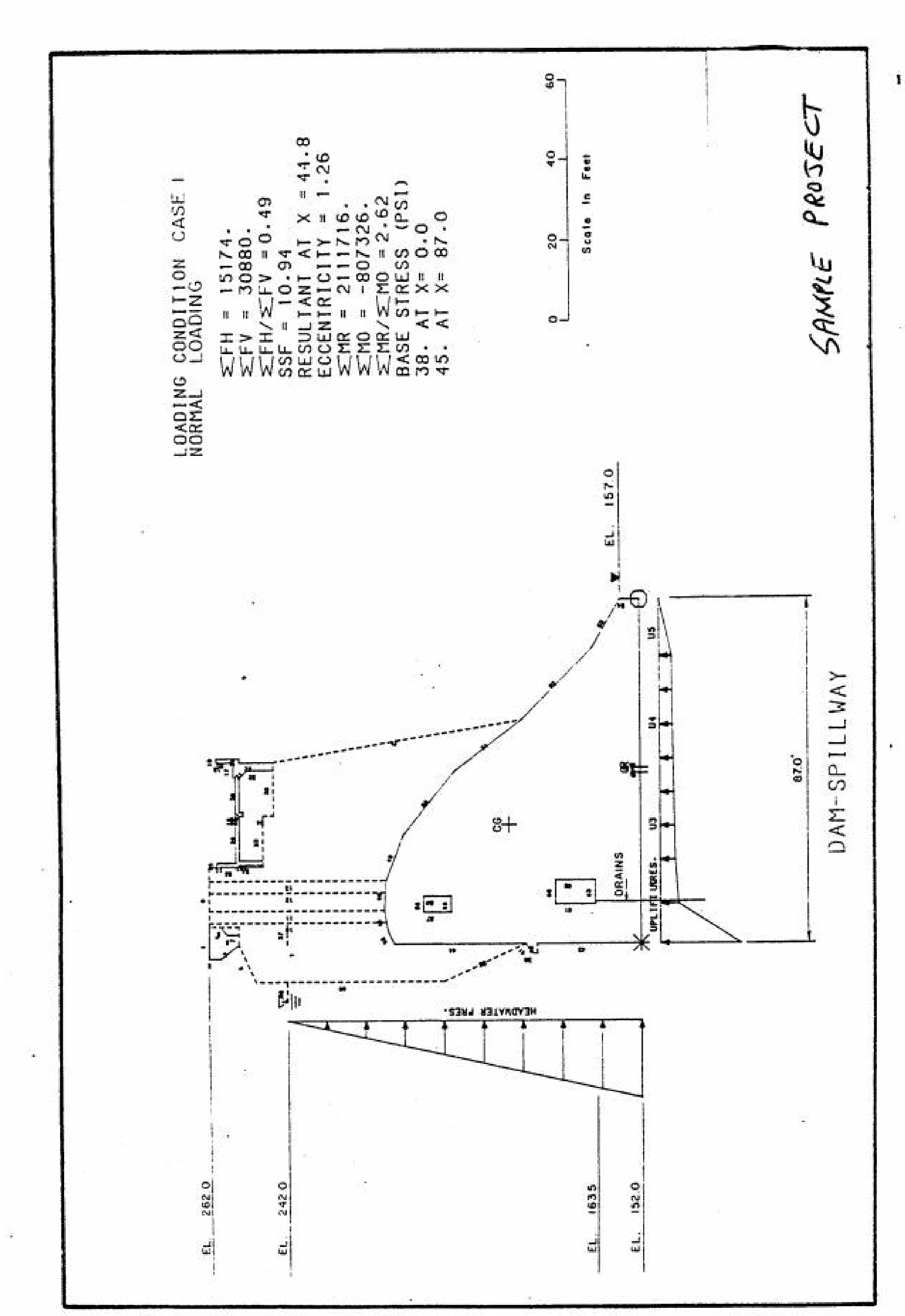
According to U.S. Army Corps of Engineers, Engineering Technical Letter No. 1110-2-256, dated June 24, 1981, which is intended to supersede portions of EM 1110-2-2200 "Gravity Dam Design" criteria, the minimum allowable $S_{s\text{-}f}$ for static loading conditions is 2.0, and for seismic loading conditions, 1.3. Typical values of "f" and "c" were taken from "The Sliding Stability of Dams" by Harald Link in Water Power Magazine, March, April & May, 1969.

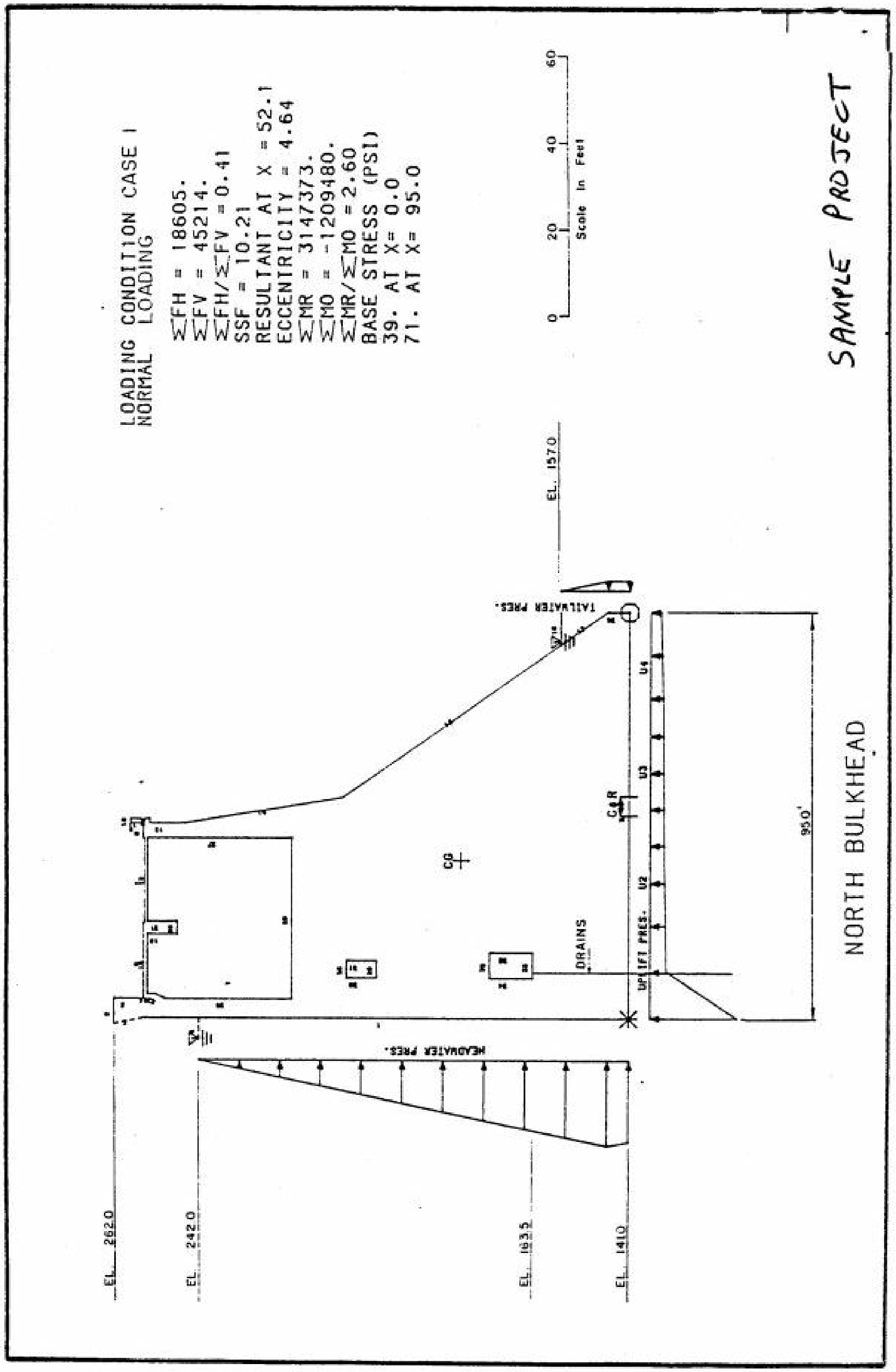
9. Bearing Pressure:

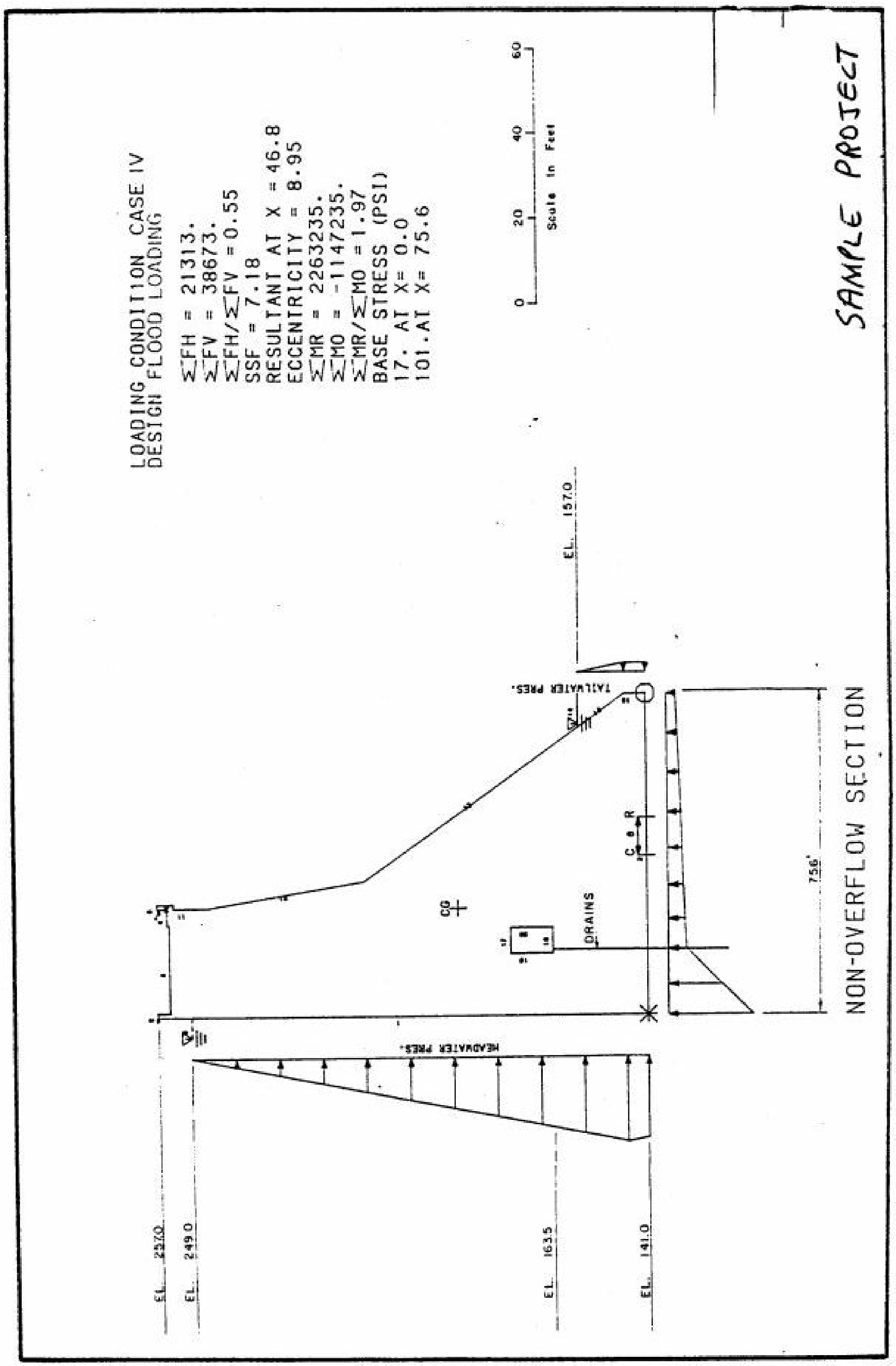
   Maximum bearing stress = 20 tsf on bedrock (278 psi).

SAMPLE PROJECT
CASES USED IN STABILITY ANALYSIS OF CONCRETE STRUCTURES

CASE I	NORMAL OPERATING WATER LEVELS
	H.W.L = 242.0
	T.W.L = 157.0
CASE II	NORMAL OPERATING LEVELS WITH ICE
	H.W.L = 242.0
	T.W.L = 157.0
	ICE LOADS 5 kips/ft
CASE III	NORMAL OPERATING WATER LEVELS WITH EARTHQUAKE
	Water Levels same as CASE I
	Horizontal acceleration due to earthquake is 0.10g
CASE IV	PROJECT DESIGN FLOOD
	H.W.L = 249.0
	T.W.L = 157.0


LOADING CONDITION CASE I
NORMAL LOADING
ΣFH = 15174.
ΣFV = 30880.
ΣFH/ΣFV = 0.49
SSF = 10.94
RESULTANT AT X = 44.8
ECCENTRICITY = 1.26
ΣMR = 2111716.
ΣMO = -807326.
ΣMR/ΣMO = 2.62
BASE STRESS (PSI)
38. AT X= 0.0
45. AT X= 87.0
0
20
40
60
Scale In Feet
SAMPLE PROJECT
EL. 157.0
EL. 262.0
EL. 242.0
EL. 163.5
EL. 152.0
HEADWATER PRES.
CG
DRAINS
UPLIFT PRES.
U3
U4
U5
87.0'
DAM-SPILLWAY


LOADING CONDITION CASE I
NORMAL LOADING
ΣFH = 18605.
ΣFV = 45214.
ΣFH/ΣFV = 0.41
SSF = 10.21
RESULTANT AT X = 52.1
ECCENTRICITY = 4.64
ΣMR = 3147373.
ΣMO = -1209480.
ΣMR/ΣMO = 2.60
BASE STRESS (PSI)
39. AT X= 0.0
71. AT X= 95.0
0
20
40
60
Scale in Feet
SAMPLE PROJECT
EL. 157.0
TAILWATER PRES.
U1
U2
U3
U4
C&R
CG
DRAINS
UPLIFT PRES.
95.0'
NORTH BULKHEAD
HEADWATER PRES.
EL. 262.0
EL. 242.0
EL. 163.5
EL. 141.0

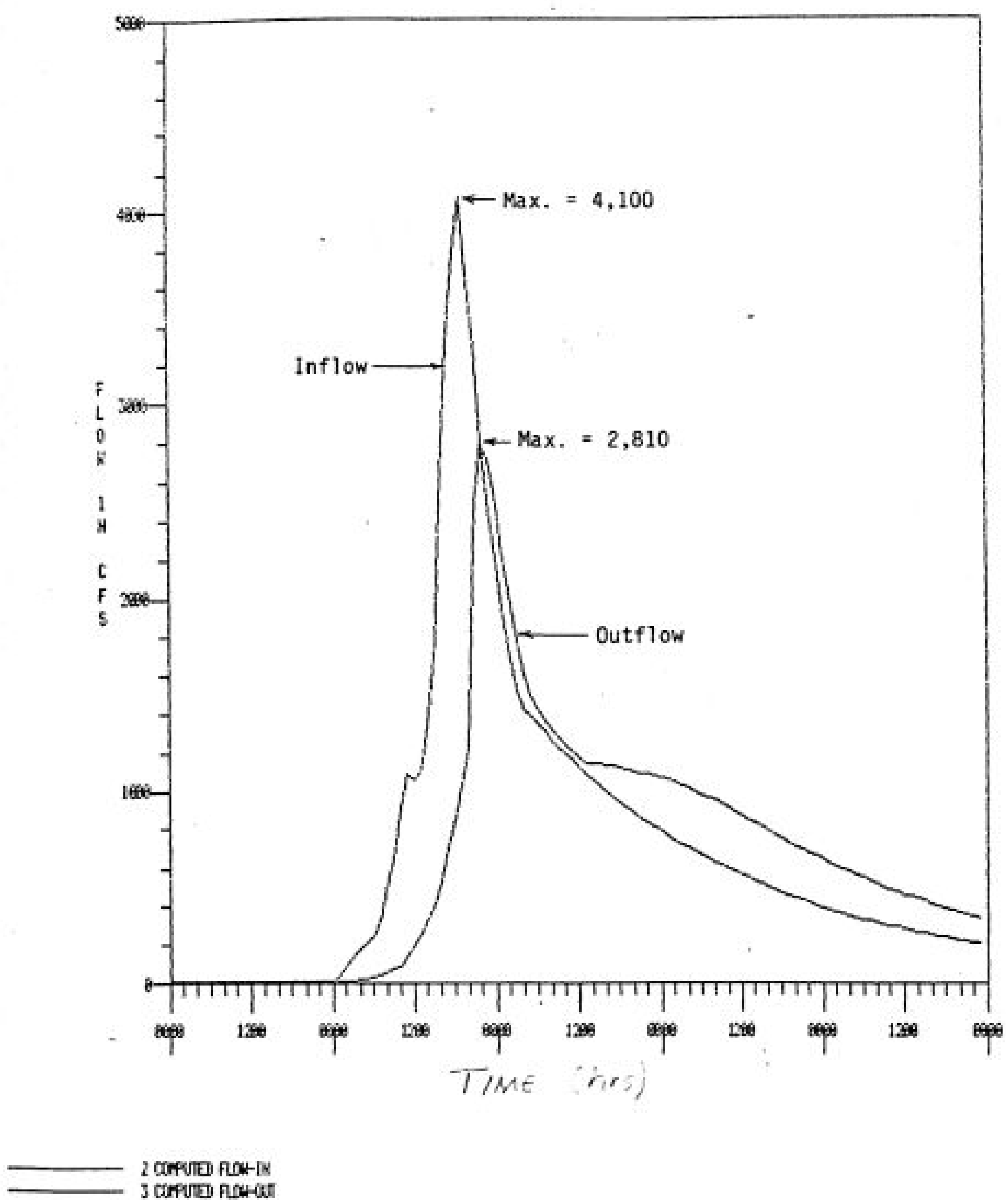

LOADING CONDITION CASE IV
DESIGN FLOOD LOADING
ΣFH = 21313.
ΣFV = 38673.
ΣFH/ΣFV = 0.55
SSF = 7.18
RESULTANT AT X = 46.8
ECCENTRICITY = 8.95
ΣMR = 2263235.
ΣMO = -1147235.
ΣMR/ΣMO = 1.97
BASE STRESS (PSI)
17. AT X= 0.0
101. AT X= 75.6
0 20 40 60
Scale in Feet
SAMPLE PROJECT
EL. 157.0
TAILWATER PRES.
CG
DRAINS
C & R
75.6'
NON-OVERFLOW SECTION
HEADWATER PRES.
EL. 257.0
EL. 249.0
EL. 163.5
EL. 141.0

SAMPLE PROJECT
STABILITY SUMMARY

CONDITION	BASE			FH (kips)	FV (kips)	FH/FV	S_{s-f}	Resultant from Downstream	M_R	M_O	M_R/M_O	BASE STRESS (psi)	
	TOT LEN	CRK LEN	EFF LEN									Upstream	Downstream
Spillway													
CASE I	87.0	0.0	87.0	15170	30880	0.49	10.94	42.24	2112000	807300	2.62	37.5	44.7
CASE II	87. 0	0.0	87.0	15170	30880	0.50	10.73	41. 38	2112000	834000	2.53	35.1	47.1
CASE III	87.0	0.0	87.0	20440	30880	0.66	8.12	36.37	2112000	988600	2.14	20. 9	61.3
CASE IV	87.o	0.0	87.0	17610	29870	0.59	9.38	38.12	2122000	987000	2.15	25.3	54.7
North Bulkhead													
CASE I	95.0	0.0	95.0	18600	45210	0.41	10.21	37.86	3147000	1209000	2.60	38.9	71.2
CASE II	95.0	0.0	95.0	18910	45210	0.42	10.04	42.20	3147000	1239000	2.54	36.6	73.5
CASE III	95.0	0.0	95.0	26010	45210	0.58	7.3	36.33	3147000	1505000	2.09	16.2	94.0
CASE IV	95.0	0.0	95.0	21320	43980	0.48	8.86	38.76	3147000	1430000	2.20	25.2	62.1
Non-Overflow Section													
CASE I	75.6	0.0	75.6	18590	37710	0.49	8.20	32.36	2249000	1028000	2.19	32.8	82.6
CASE II	75.6	0.0	75.6	18890	37710	0.50	8.07	31.55	2249000	1058000	2.12	29.1	86.3
CASE III	75.6	1.2	74.4	25100	37710	0.67	5.99	24.80	2249000	1513000	1.71	0.0	117.3
CASE IV	75.6	0.0	75.6	21310	38670	0.55	7.18	28.80	2263000	1147000	1.97	17.0	101.1

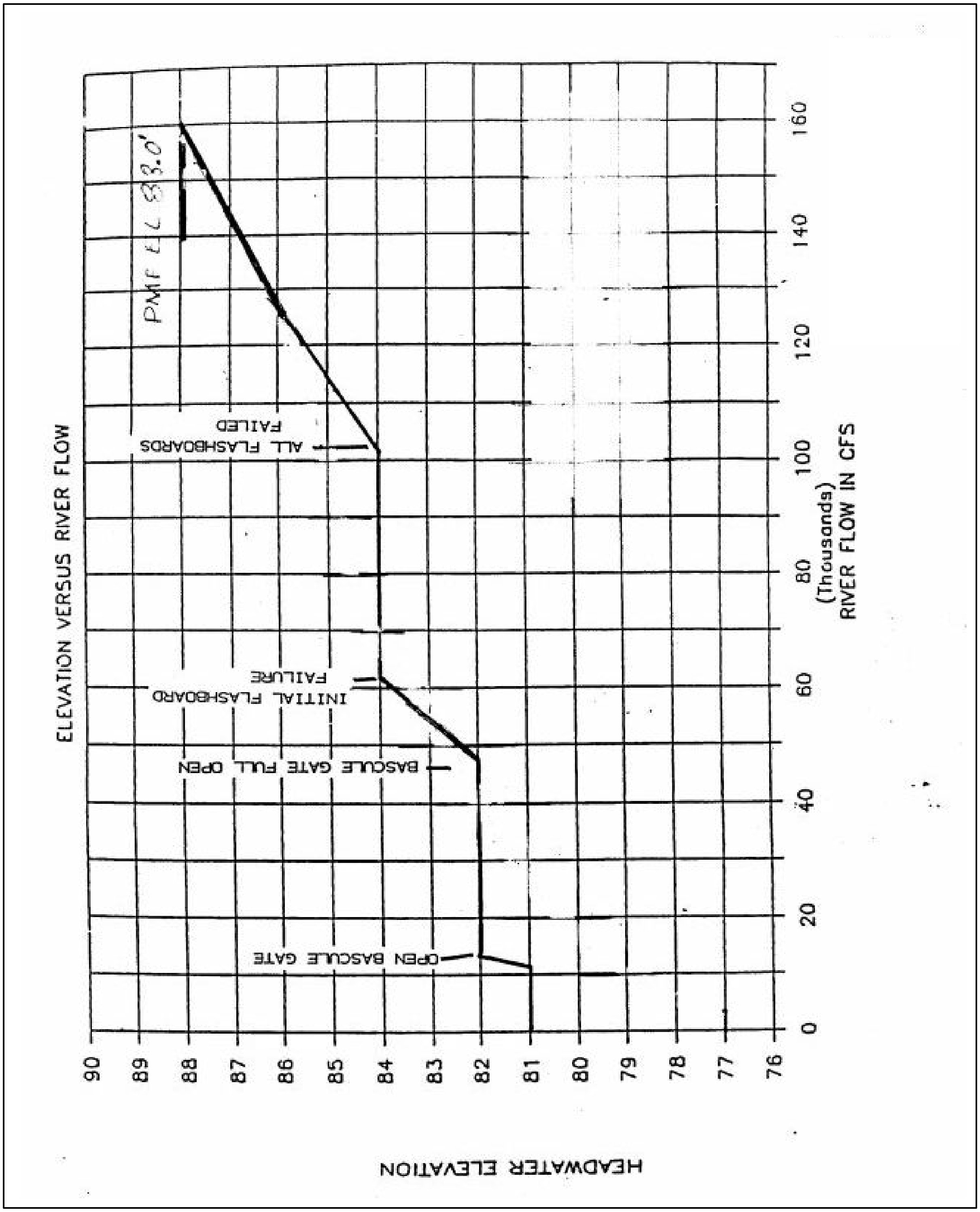
Attachment 4

Example of Summary of Hydrologic and Hydraulic Information

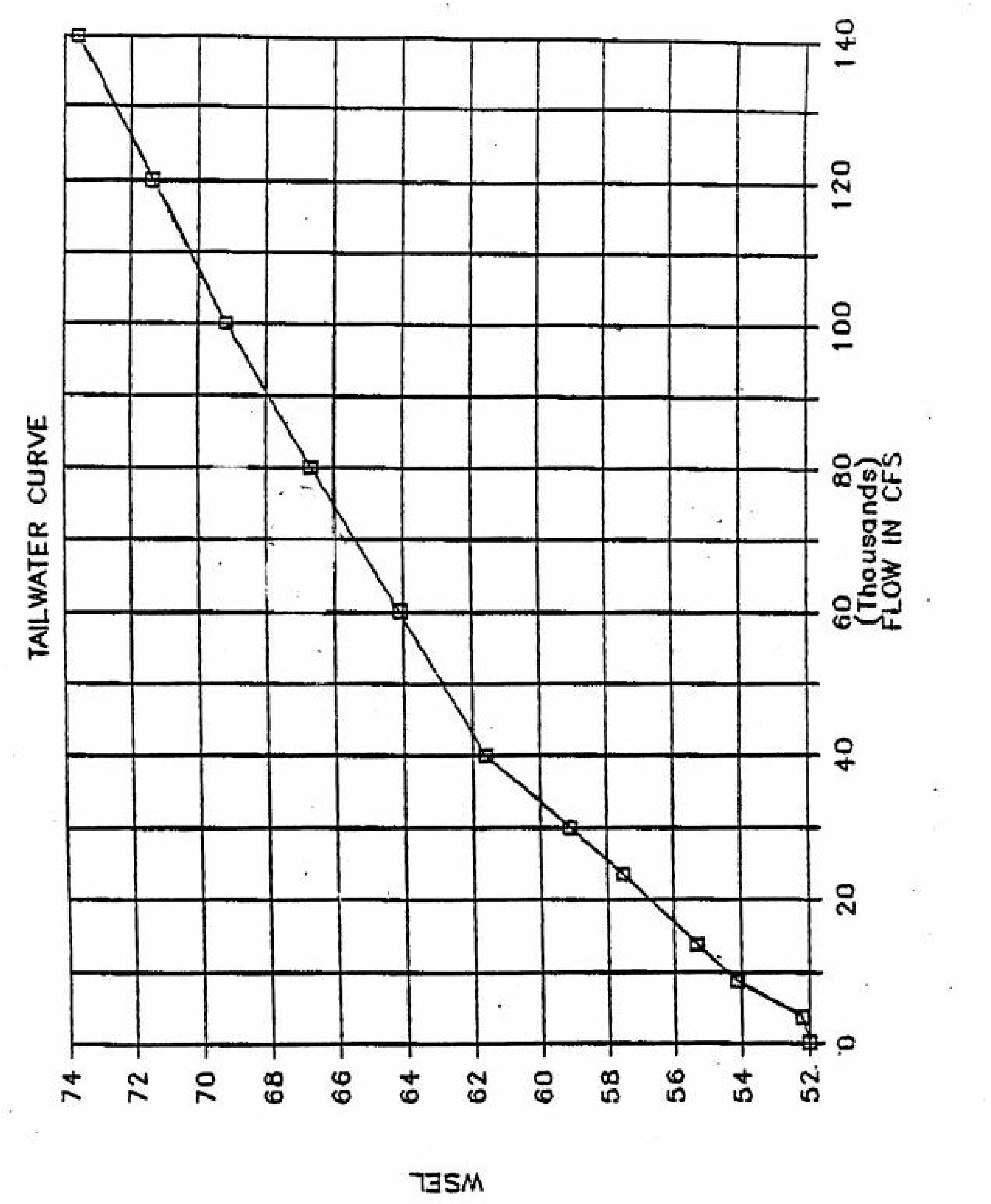


Inflow/Outflow Hydrograph
for General Storm PMF

SAMPLE PROJECT



SAMPLE PROJECT
SPILLWAY RATING CURVE



SAMPLE PROJECT
TAILWATER RATING CURVE

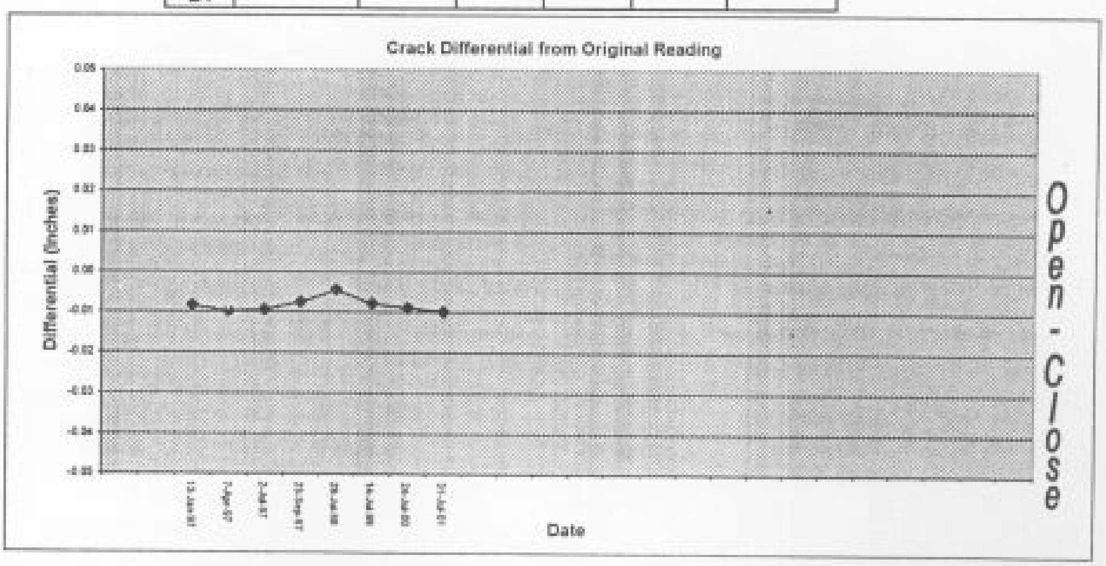
Attachment 5

Example of Summary
of
Instrumentation and Surveillance Information

SAMPLE PROJECT

Crack Measurement Station No. 1
Initial Reading: 5.900
Date: 12-29-81

No.	Date	Reading By	Measurements (Inches) 1	2	Average	Diff. From Original Reading
1	13-Jan-97	HTG	5.891	5.892	5.892	-0.008
2	7-Apr-97	HTG	5.890	5.890	5.890	-0.010
3	2-Jul-97	HTG	5.890	5.891	5.891	-0.010
4	23-Sep-97	HTG	5.893	5.892	5.893	-0.008
5	28-Jul-98	HTG	5.896	5.895	5.896	-0.005
6	14-Jul-99	HTG	5.892	5.892	5.892	-0.008
7	24-Jul-00	HTG	5.891	5.891	5.891	-0.009
8	31-Jul-01	HTG	5.890	5.891	5.890	-0.010
9						
10						
11						
12						
13						
14						
15						
16						
17						
18						
19						
20						
21						
22						
23						
24						



SAMPE PROJECT – . Embankment Seepage Weir

Weir Box Location: . embankment. (Twice annually).

Date	Elevation (ft., USGS)	Weir Box Flow (inches)	Checked by:	Comments
28-Jul-97	491.01	2.50	KWL	Area below toe wet.
4-Aug-97	491.31	2.25	KWL	Area below toe wet.
12-Aug-97	491.45	2.25	KWL	Area below toe wet.
6-Nov-97	485.27	1.00	KWL	Area below toe damp.
20-May-98	491.40	1.75	KWL	
17-Jun-98	491.18	2.00	KWL	
23-Sep-98	487.12	2.00	KWL	
28-Aug-99	490.01	2.00	KWL	
15-Jun-00	490.87	2.00	KWL	
27-Aug-00	490.35	2.50	KWL	
21-May-01	487.83	1.50	KWL	
25-Aug-01	488.24	2.50	KWL	

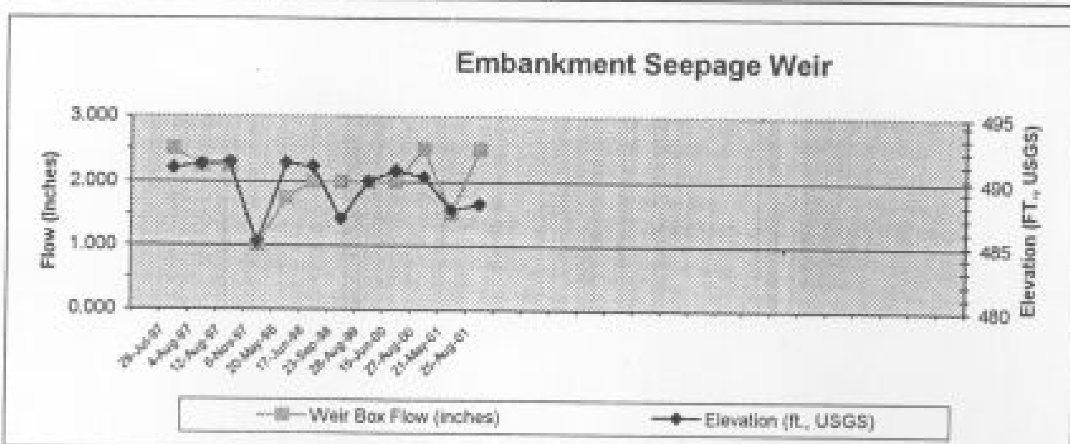
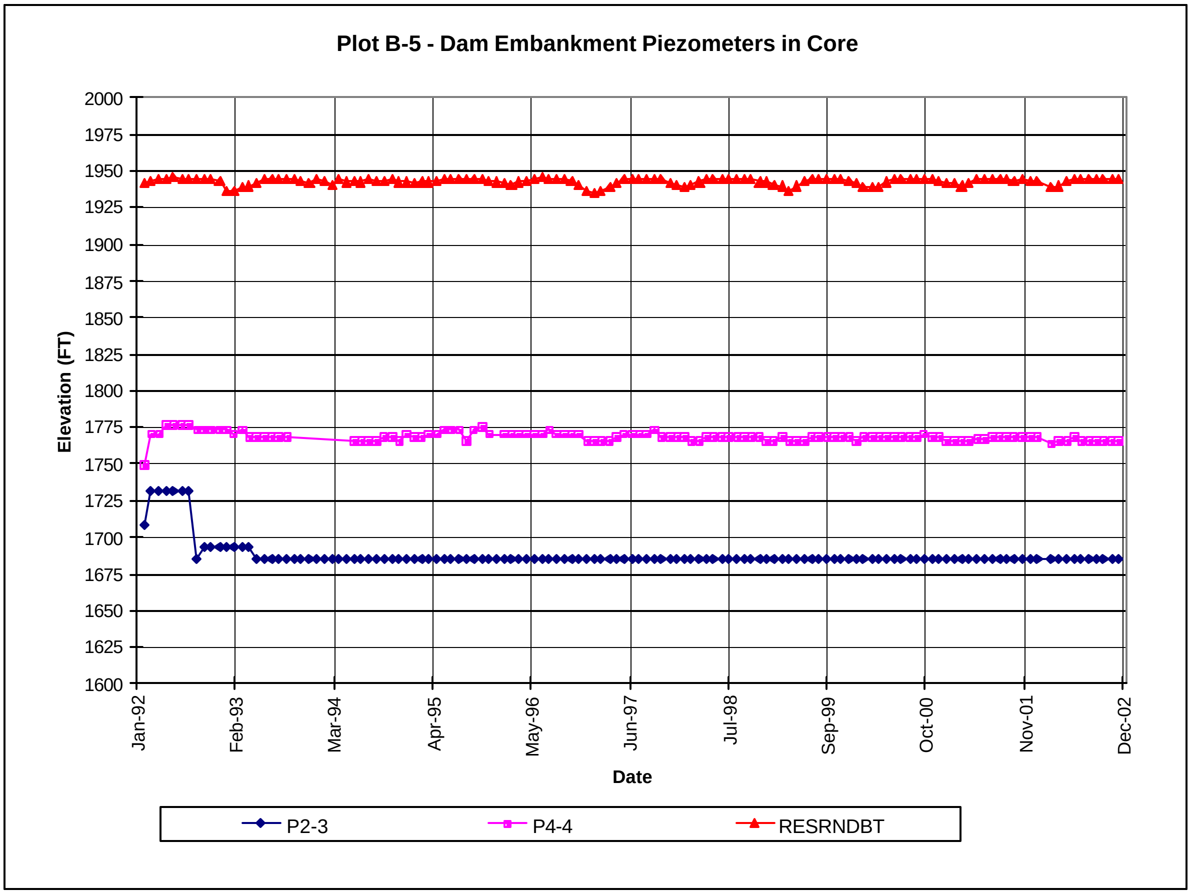


TABLE 1 - PIEZOMETER READINGS

PIEZO	DATE	PRESS (psi)	PIEZO ELEV (ft)
P2-3	1/30/1997	0.0	1685.0
P2-3	2/28/1997	0.0	1685.0
P2-3	3/30/1997	0.0	1685.0
P2-3	4/30/1997	0.0	1685.0
P2-3	5/30/1997	0.0	1685.0
P2-3	6/30/1997	0.0	1685.0
P2-3	7/30/1997	0.0	1685.0
P2-3	8/30/1997	0.0	1685.0
P2-3	9/30/1997	0.0	1685.0
P2-3	10/30/1997	0.0	1685.0
P2-3	11/30/1997	0.0	1685.0
P2-3	12/30/1997	0.0	1685.0
P2-3	1/30/1998	0.0	1685.0
P2-3	2/28/1998	0.0	1685.0
P2-3	3/30/1998	0.0	1685.0
P2-3	4/30/1998	0.0	1685.0
P2-3	5/30/1998	0.0	1685.0
P2-3	6/30/1998	0.0	1685.0
P2-3	7/30/1998	0.0	1685.0
P2-3	8/30/1998	0.0	1685.0
P2-3	9/30/1998	0.0	1685.0
P2-3	10/30/1998	0.0	1685.0
P2-3	11/30/1998	0.0	1685.0
P2-3	12/30/1998	0.0	1685.0
P2-3	1/30/1999	0.0	1685.0
P2-3	2/28/1999	0.0	1685.0
P2-3	3/30/1999	0.0	1685.0
P2-3	4/30/1999	0.0	1685.0
P2-3	5/30/1999	0.0	1685.0
P2-3	6/30/1999	0.0	1685.0
P2-3	7/30/1999	0.0	1685.0
P2-3	8/30/1999	0.0	1685.0
P2-3	9/30/1999	0.0	1685.0
P2-3	10/30/1999	0.0	1685.0
P2-3	11/30/1999	0.0	1685.0
P2-3	12/30/1999	0.0	1685.0
P2-3	1/27/2000	0.0	1685.0
P2-3	2/29/2000	0.0	1685.0
P2-3	3/31/2000	0.0	1685.0
P2-3	4/27/2000	0.0	1685.0
P2-3	5/30/2000	0.0	1685.0
P2-3	6/27/2000	0.0	1685.0
P2-3	7/31/2000	0.0	1685.0

PIEZO	DATE	PRESS (psi)	PIEZO ELEV (ft)
P4-4	8/30/1997	37.0	1770.5
P4-4	9/30/1997	38.0	1772.8
P4-4	10/30/1997	36.0	1768.2
P4-4	11/30/1997	36.0	1768.2
P4-4	12/30/1997	36.0	1768.2
P4-4	1/30/1998	36.0	1768.2
P4-4	2/28/1998	35.0	1765.9
P4-4	3/30/1998	35.0	1765.9
P4-4	4/30/1998	36.0	1768.2
P4-4	5/30/1998	36.0	1768.2
P4-4	6/30/1998	36.0	1768.2
P4-4	7/30/1998	36.0	1768.2
P4-4	8/30/1998	36.0	1768.2
P4-4	9/30/1998	36.0	1768.2
P4-4	10/30/1998	36.0	1768.2
P4-4	11/30/1998	36.0	1768.2
P4-4	12/30/1998	35.0	1765.9
P4-4	1/30/1999	35.0	1765.9
P4-4	2/28/1999	36.0	1768.2
P4-4	3/30/1999	35.0	1765.9
P4-4	4/30/1999	35.0	1765.9
P4-4	5/30/1999	35.0	1765.9
P4-4	6/30/1999	36.0	1768.2
P4-4	7/30/1999	36.0	1768.2
P4-4	8/30/1999	36.0	1768.2
P4-4	9/30/1999	36.0	1768.2
P4-4	10/30/1999	36.0	1768.2
P4-4	11/30/1999	36.0	1768.2
P4-4	12/30/1999	35.0	1765.9
P4-4	1/27/2000	36.0	1768.2
P4-4	2/29/2000	36.0	1768.2
P4-4	3/31/2000	36.0	1768.2
P4-4	4/27/2000	36.0	1768.2
P4-4	5/30/2000	36.0	1768.2
P4-4	6/27/2000	36.0	1768.2
P4-4	7/31/2000	36.0	1768.2
P4-4	8/30/2000	36.0	1768.2
P4-4	9/29/2000	37.0	1770.5
P4-4	10/30/2000	36.0	1768.2
P4-4	11/29/2000	36.0	1768.2
P4-4	12/27/2000	35.0	1765.9
P4-4	2/1/2001	35.0	1765.9
P4-4	2/28/2001	35.0	1765.9



PLOT of PIEZOMETER READINGS

SAMPLE PROJECT

Settlement Point No. 8
Initial Elev: 304.15
Date: 12-31-81

No.	Date	Survey By	All Elevations USGS Reservior Elev.	Settlement Point Elev.	Initial Elev.
1	15-Jan-97	HTG	335.87	304.15	304.15
2	8-Apr-97	HTG	335.83	304.15	304.15
3	2-Jul-97	HTG	335.95	304.16	304.15
4	23-Sep-97	HTG	332.06	304.16	304.15
5	8-Jul-98	HTG	336.01	304.15	304.15
6	14-Jul-99	HTG	336.02	304.15	304.15
7	25-Jul-00	HTG	336.08	304.15	304.15
8	31-Jul-01	HTG	336.06	304.15	304.15
9					304.15
10					304.15
11					304.15
12					304.15
13					304.15
14					304.15
15					304.15
16					304.15
17					304.15
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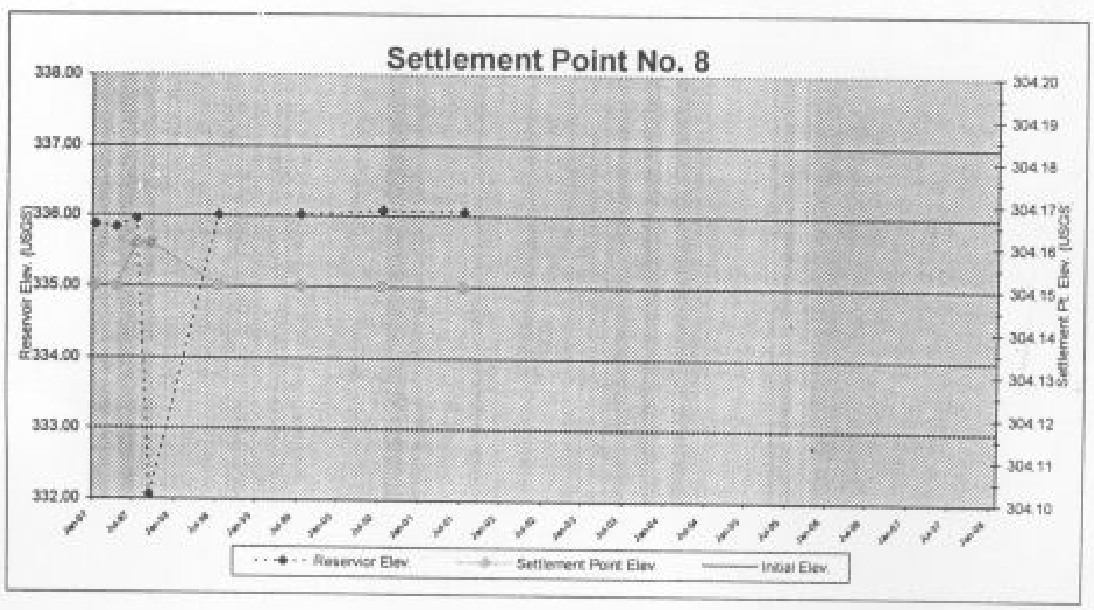
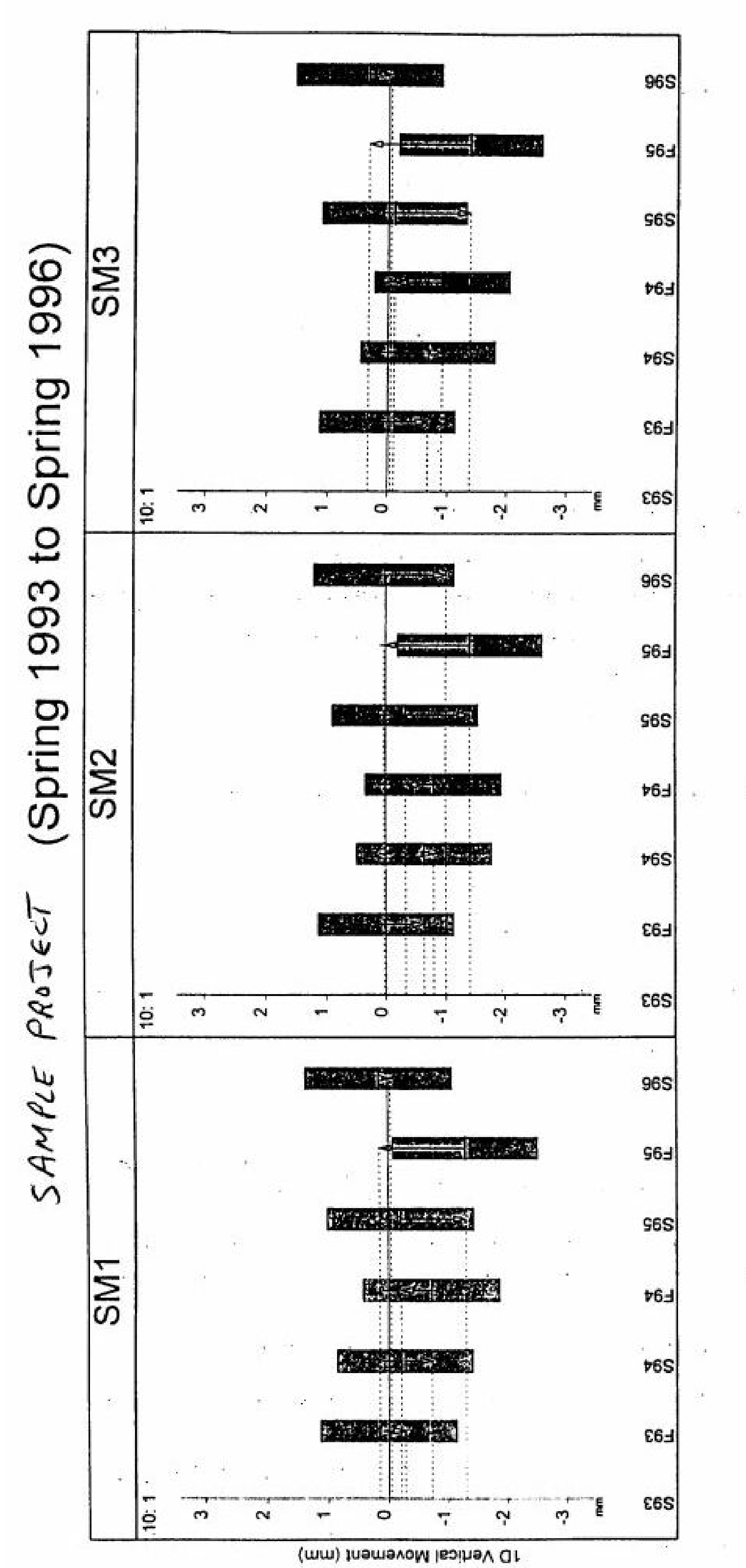
19					304.15
20					304.15
21					304.15
22					304.15
23					304.15
24					304.15



SAMPLE PROJECT

Summary of Vertical Movements (Spring 1993 to Spring 1996)

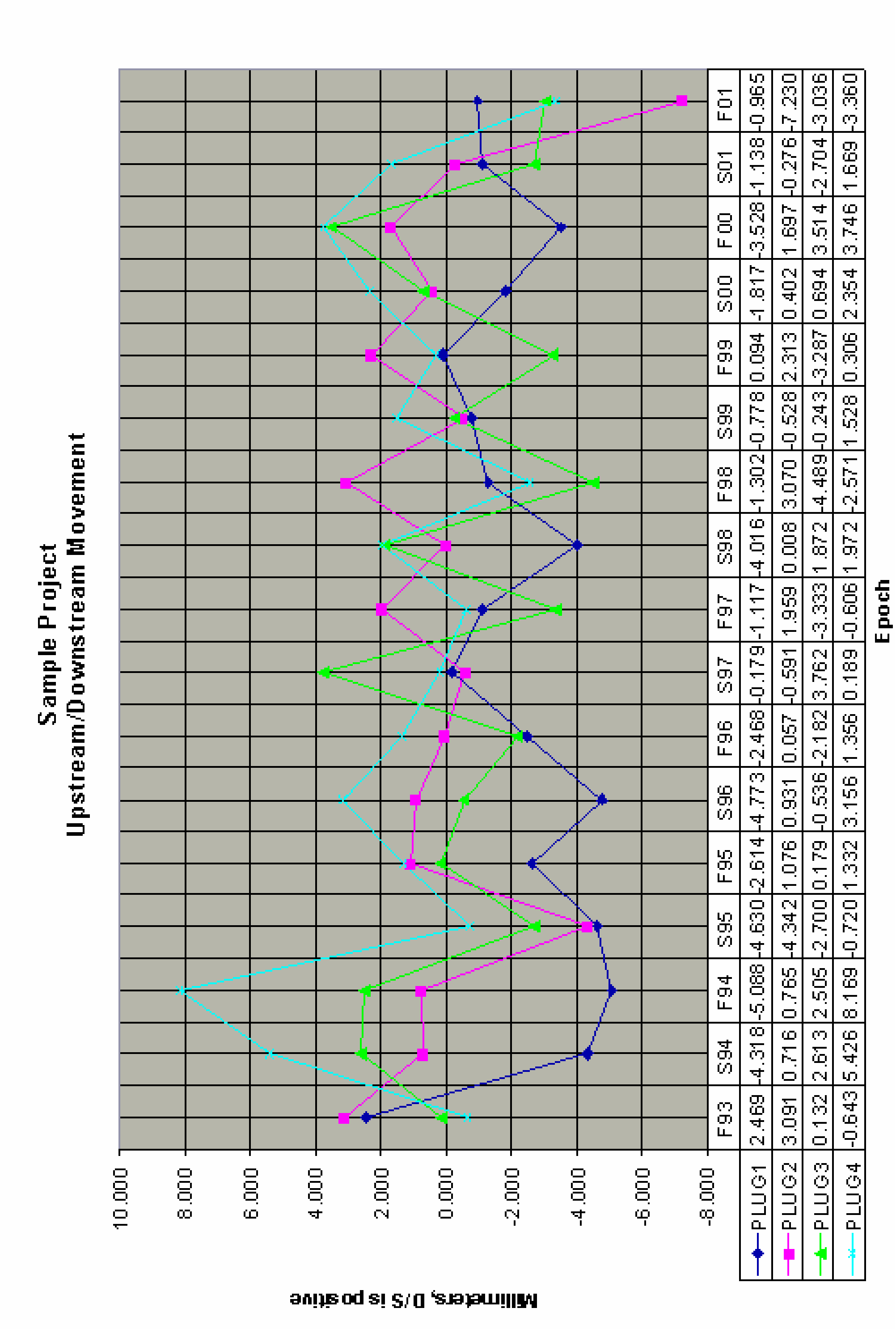
Point	To / From	F93 A=> (mm)	95% Conf. Region (mm)	S94 A=> (mm)	95% Conf. Region (mm)	F94 A=^ (mm)	95% Conf. Region (mm)
SM1	S93	-0.278	1.134	-0.426	1.159	-0.212	1.143
	Incremental	-0.278	1.134	-0.444	1.133	0.511	1.142
SM2	S93	-0.641	1.130	-0.502	1.157	-0.330	1.138
	Incremental	-0.641	1.130	-0.159	1.130	0.470	1.138
SM3	S93	-0.672	1.130	-0.609	1.158	-0.105	1.136
	Incremental	-0.672	1.130	-0.234	1.128	0.801	1.135
SM4	S93	-0.94	1.140	-0.946	1.185	-0.364	1.145
	Incremental	-0.94	1.140	-0.359	1.140	0.936	1.145
SM5	S93	-1.388	1.138	-0.853	1.185	-0.399	1.143
	Incremental	-1.388	1.138	-0.183	1.138	0.807	1.143
SM6	S93	-0.887	1.136	-0.548	1.184	-0.278	1.140
	Incremental	-0.887	1.136	-0.014	1.137	0.623	1.141
SM7	S93	-0.893	1.135	-0.119	1.184	-0.196	1.138
	Incremental	-0.893	1.135	0.421	1.135	0.276	1.138
WP1	S93	0.210	0.843	-0.209	0.750	-0.111	0.853
	Incremental	0.210	0.843	-0.790	0.843	0.468	0.853
WP2	S93	0.057	0.845	1.224	1.184	0.390	0.848
	Incremental	0.057	0.845	0.815	0.845	-0.482	0.848
MM6	S93	-0.236	0.777	0.188	0.672	-0.228	0.781
	Incremental	-0.236	0.777	0.023	0.777	-0.015	0.782
MM7	S93	-0.031	0.124	0.022	0.078	-0.051	0.125
	Incremental	-0.031	0.124	-0.048	0.124	0.028	0.125


SAMPLE PROJECT (Spring 1993 to Spring 1996)
SM1
SM2
SM3
1D Vertical Movement (mm)

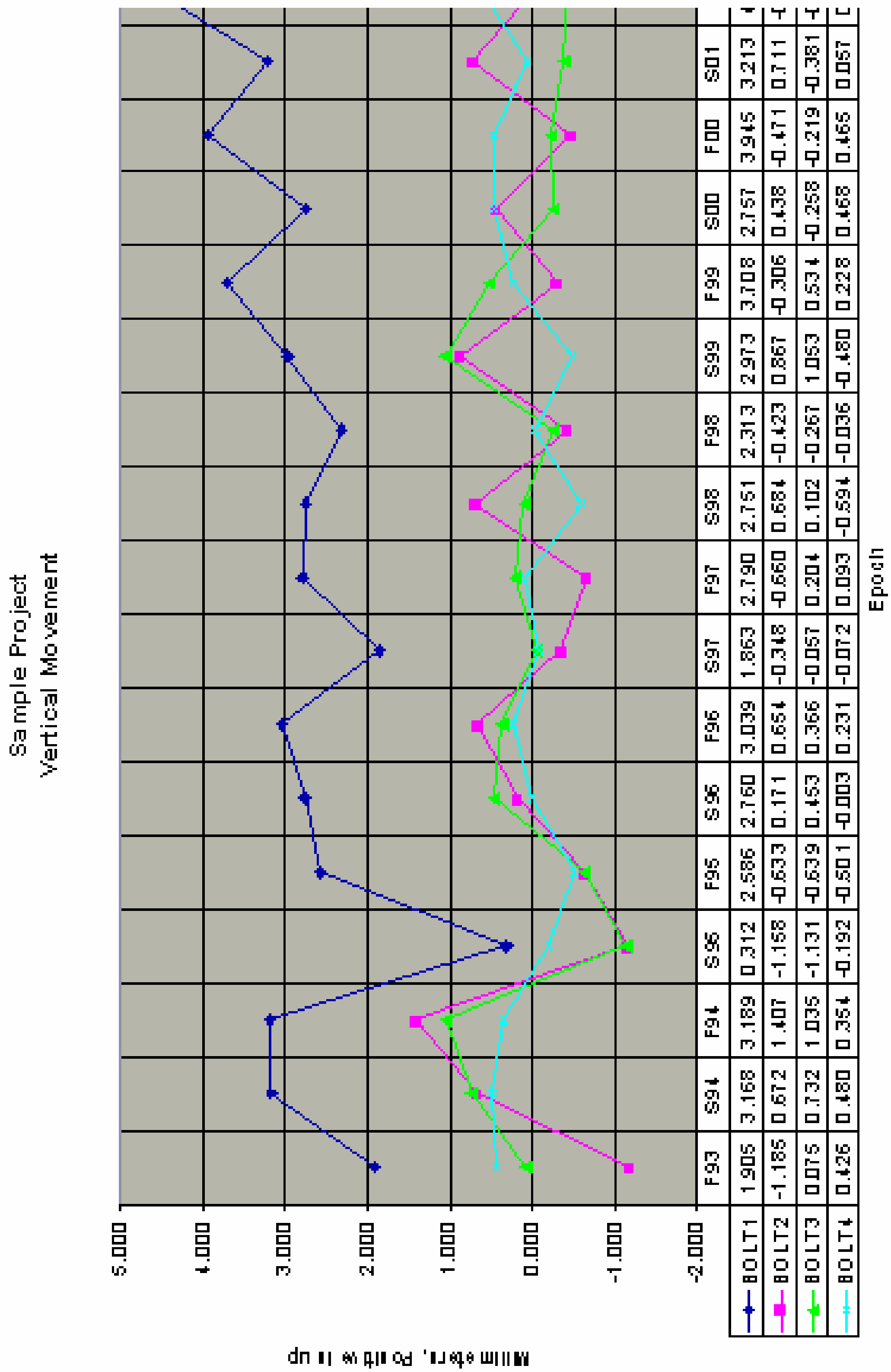
SAMPLE PROJECT

Summary of Horizontal Movements (Spring 1993 to Spring 1996)

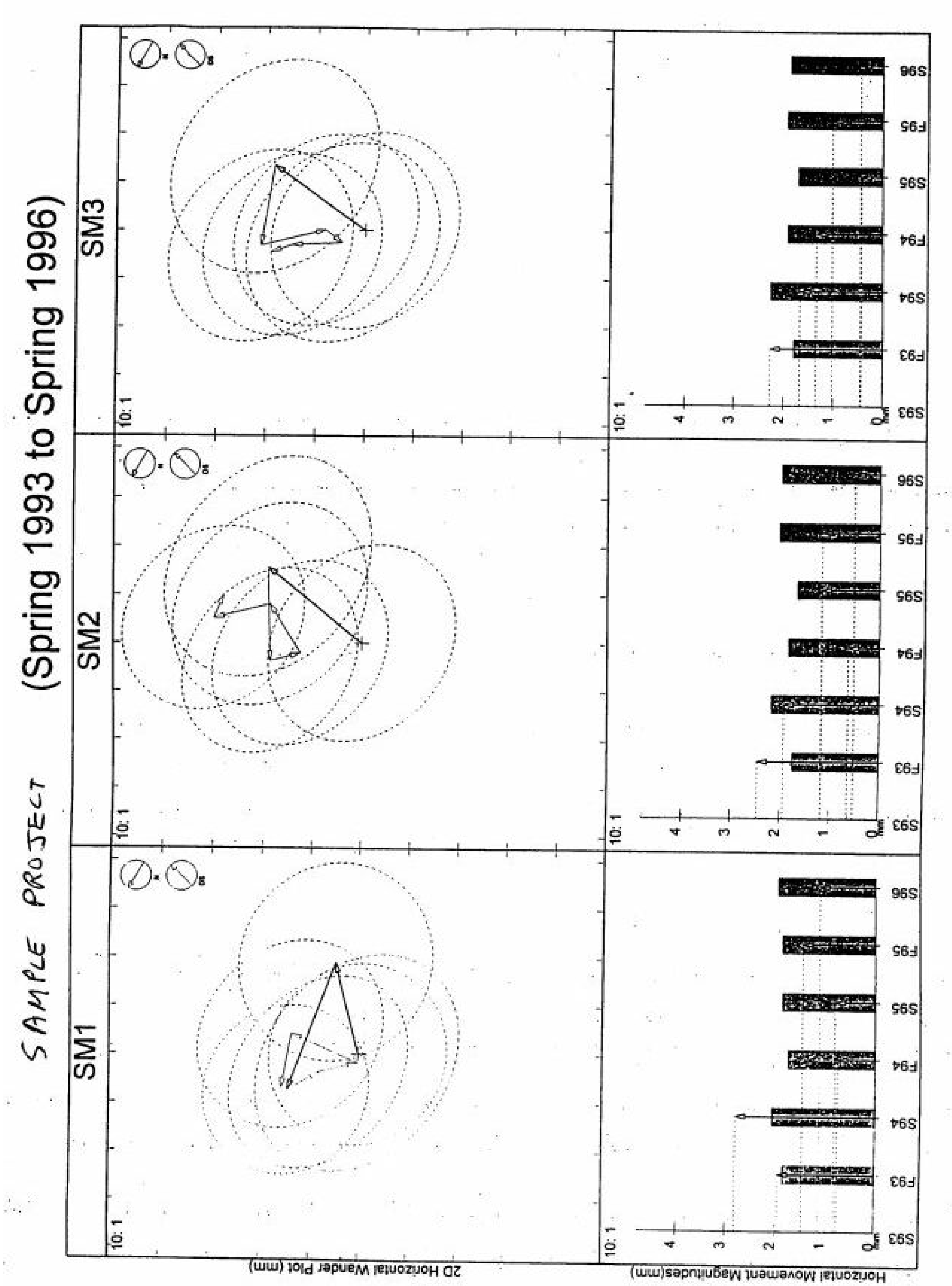
Point	To / From	F93 A=> (mm)	Direction (degrees)	95% Conf. Region (mm)	S94 A=> (mm)	Direction (degrees)	95% Conf. Region (mm)	F94 A=^ (mm)	Direction (degrees)	95% Conf. Region (mm)
SM1	S93	1.955	76	1.85	0.846	329	1.751	0.935	352	1.582
	Incremental	1.955	76	1.85	2.813	290	2.073	0.752	149	1.746
SM2	S93	2.463	39	1.752	1.227	356	1.742	1.389	0	1.606
	Incremental	2.463	39	1.752	1.933	268	2.182	0.627	165	1.833
SM3	S93	2.277	35	1.793	1.593	357	1.782	0.981	13	1.658
	Incremental	2.277	35	1.793	1.677	279	2.264	1.353	165	1.922
SM4	S93	1.797	32	1.802	1.286	12	1.749	1.028	331	1.742
	Incremental	1.797	32	1.802	0.943	280	2.157	1.204	218	1.682
SM5	S93	1.004	36	1.798	0.739	96	1.982	0.776	351	1.723
	Incremental	1.004	36	1.798	0.555	187	2.071	0.904	291	2.11
SM6	S93	1.487	84	1.447	0.935	64	1.376	1.776	356	1.705
	Incremental	1.487	84	1.447	0.947	300	1.868	1.361	314	1.719
SM7	S93	2.942	57	1.779	0.288	124	1.875	2.003	2	1.625
	Incremental	2.942	57	1.779	2.896	235	1.867	1.877	354	1.762
WP1	S93	2.355	56	1.821	0.63	299	1.318	1.089	33	1.197
	Incremental	2.355	56	1.821	2.839	265	1.96	1.268	102	1.375
WP2	S93	3.648	133	1.781	1.946	214	1.645	2.515	277	1.591
	Incremental	3.648	133	1.781	3.953	282	1.848	2.291	320	1.734
MM6	S93	0.557	215	1.308	0.84	299	1.308	0.236	231	1.204
	Incremental	0.557	215	1.308	0.988	312	1.447	0.906	131	1.337
MM7	S93	1.053	289	1.426	0.997	158	1.374	0.708	211	1.115
	Incremental	1.053	289	1.426	1.152	147	1.73	0.312	234	1.29
MM8	S93	0.346	249	0.961	4.087	242	3.494	0.395	262	0.916
	Incremental	0.346	249	0.961	0.605	245	1.052	0.732	52	0.907
MM9	S93	0.18	63	1.458	-0.218	159	0.651	0.357	107	1.511
	Incremental	0.18	63	1.458	1.468	87	1.808	1.315	255	1.498



	F93	S94	F94	S95	F95	S96	F96	S97	F97	S98	F98	S99	F99	S00	F00	S01	F01
PLUG1	2.469	-4.318	-5.088	-4.630	-2.614	-4.773	-2.468	-0.179	-1.117	-4.016	-1.302	-0.778	0.094	-1.817	-3.528	-1.138	-0.965
PLUG2	3.091	0.716	0.765	-4.342	1.076	0.931	0.057	-0.591	1.959	0.008	3.070	-0.528	2.313	0.402	1.697	-0.276	-7.230
PLUG3	0.132	2.613	2.505	-2.700	0.179	-0.536	-2.182	3.762	-3.333	1.872	-4.489	-0.243	-3.287	0.694	3.514	-2.704	-3.036
PLUG4	-0.643	5.426	8.169	-0.720	1.332	3.156	1.356	0.189	-0.606	1.972	-2.571	1.528	0.306	2.354	3.746	1.669	-3.360



	F93	S94	F94	S95	F95	S96	F96	S97	F97	S98	F98	S99	F99	S00	F00	S01
BOLT1	1.905	3.168	3.189	0.312	2.586	2.760	3.039	1.863	2.790	2.751	2.313	2.973	3.708	2.757	3.945	3.213
BOLT2	-1.185	0.672	1.407	-1.158	-0.633	0.171	0.654	-0.348	-0.660	0.684	-0.423	0.867	-0.306	0.438	-0.471	0.711
BOLT3	0.075	0.732	1.035	-1.131	-0.639	0.453	0.366	-0.057	0.204	0.102	-0.267	1.053	0.534	-0.258	-0.219	-0.381
BOLT4	0.426	0.480	0.354	-0.192	-0.501	-0.003	0.231	-0.072	0.093	-0.594	-0.036	-0.480	0.228	0.468	0.465	0.057


SAMPLE PROJECT
(Spring 1993 to Spring 1996)
SM1
SM2
SM3
2D Horizontal Wander Plot (mm)
Horizontal Movement Magnitudes(mm)
S93
F93
S94
F94
S95
F95
S96

Attachment 6

Example of Document Control Log Sheets

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The person or organization to whom this manual
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LITTLE POWER COMPANY

Big Power Project: FERC No. XYZ

Supporting Technical Information Change No. ____

Section	Instructions	Summary of Changes
Table of Contents	Remove previously issued Table of Contents (6/18/2002) and replace with Table of Contents dated 1/22/2003 rev. 1	Updates revision numbers and effective dates
Section 1 Failure Modes Analysis	Insert Addenda 1, Failure Mode 7 dated 1/2/2003	Addends Failure Modes Analysis Report to include new Failure Mode 7

SUPPORTING TECHNICAL INFORMATION

REVISION LOG NOTICE

BIG POWER PROJECT

Revised Item	Date Entered	Initials	Date Read	Initials