



Federal Energy Regulatory Commission Division of Dam Safety and Inspections



Overview of FERC Instrumentation Program



Federal Energy Regulatory Commission Division of Dam Safety and Inspections



Section 12.41 of Chapter 18 of the CFR 'Monitoring instruments'.

- “(a) In designing a project, a licensee must make adequate provision for installing and maintaining appropriate monitoring instrumentation whenever any physical condition that might affect the stability of a project structure has been discovered or is anticipated. The instrumentation must be satisfactory to the Regional Engineer...”



Federal Energy Regulatory Commission Division of Dam Safety and Inspections



FERC Instrumentation Program

- FERC Engineering Guidelines
 - Chapter 9 Instrumentation & Monitoring
 - Chapter 14 Monitoring the Performance of Dams
 - Appendix J and K DSSMP and DSSMR
- FERC Operating Manual Chapter 3
 - Operation Inspection & Report
 - Special Instrumentation Inspection & Report



Federal Energy Regulatory Commission Division of Dam Safety and Inspections



Chapter 9

FERC Engineering Guidelines

- Developed and published in 1994
- Philosophy of Instrumentation:
“The purpose of I & M is to maintain and improve dam safety by providing information to:
 - 1) evaluate whether a dam is performing as expected and
 - 2) warn of changes that could endanger the safety of a dam.”



Federal Energy Regulatory Commission Division of Dam Safety and Inspections



Chapter 9 FERC Engineering Guidelines

- Purpose of Chapter...
“...Provide staff engineers with recommended guidelines to use in reviewing and evaluating....
instrumentation and monitoring programs...”



Federal Energy Regulatory Commission Division of Dam Safety and Inspections



Instrumentation typically provides data to:

From Chapter 9:

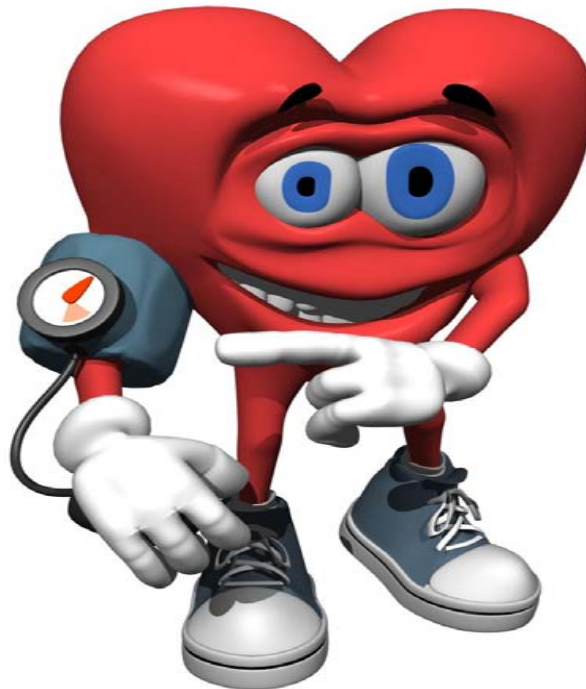
- characterize site conditions before construction;
- verify design and analysis assumptions;
- evaluate behavior during construction, first filling, and operation of the structure;
- evaluate performance of specific design features;
- observe performance of known geological and structural anomalies; and
- evaluate performance with respect to **potential** site-specific **failure modes**.



Federal Energy Regulatory Commission Division of Dam Safety and Inspections



Blood Pressure and Temperature ...



Instruments and inspections for the *Dam's General Health*

Looking for "...the unknown unknowns..."



Federal Energy Regulatory Commission Division of Dam Safety and Inspections



Chapter 9 presents:

- the philosophy of instrumentation and monitoring,
- commonly used instruments
- instrumentation system design,
- monitoring schedule guidelines,
- data processing and evaluation,
- automated data acquisition,
- and examples of acceptable instrumentation and data presentation.



Federal Energy Regulatory Commission Division of Dam Safety and Inspections



Chapter 9 presents:

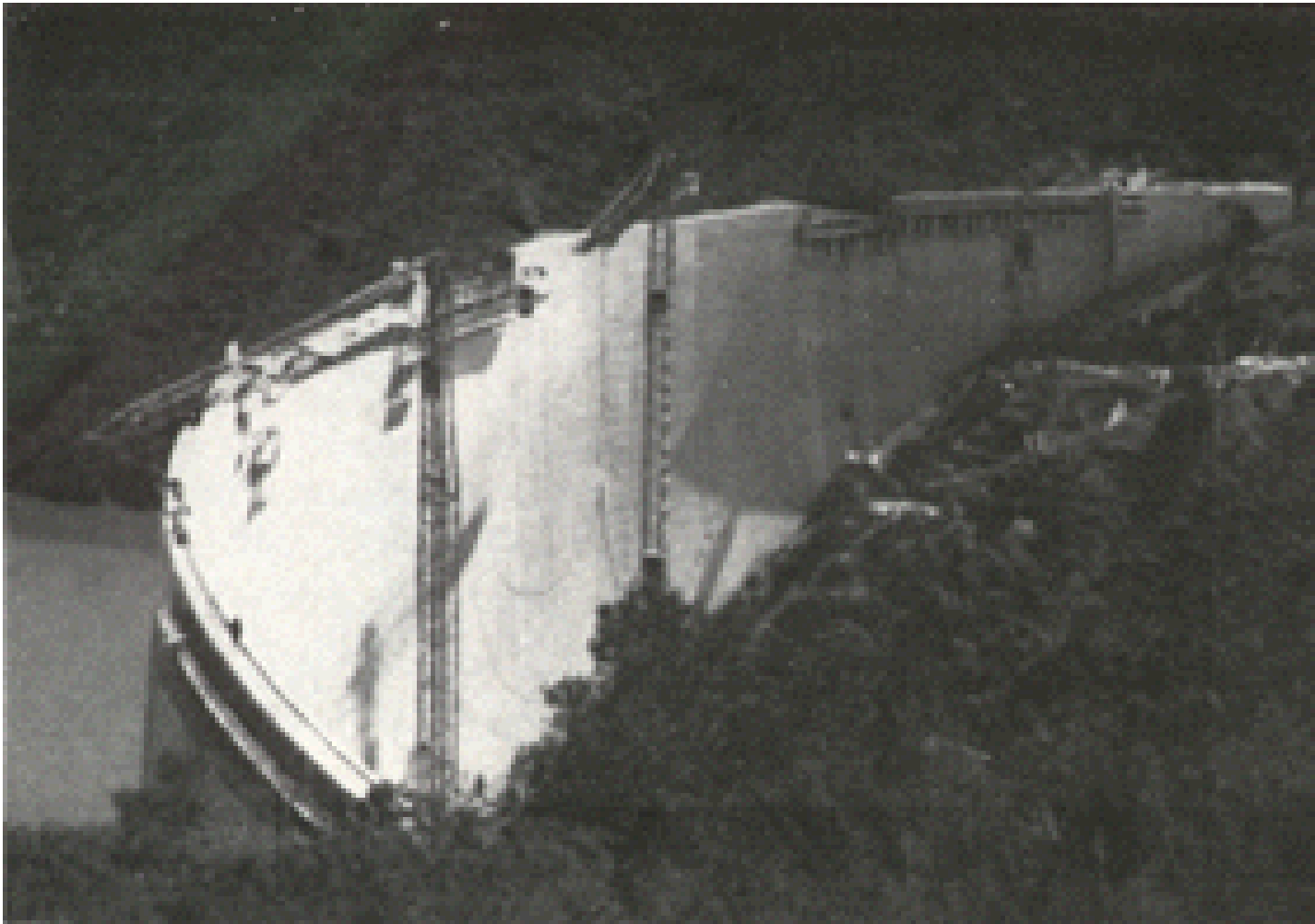
- Dated, but still valid:
 - technical section on instruments, movements and measurements
 - ADAS
- Helpful guidance:
 - minimum instrumentation for dams
 - instruments/monitoring for problems
- Not addressed: GPS, LIDAR, new millennia tech
- Update, Combine or Retire?



Federal Energy Regulatory Commission Division of Dam Safety and Inspections



Dam Quiz? No. 1





Federal Energy Regulatory Commission Division of Dam Safety and Inspections



Chapter 14 FERC Engineering Guidelines Dam Safety Performance Monitoring Program

"failure mode thinking"
Officially Born July 1, 2005





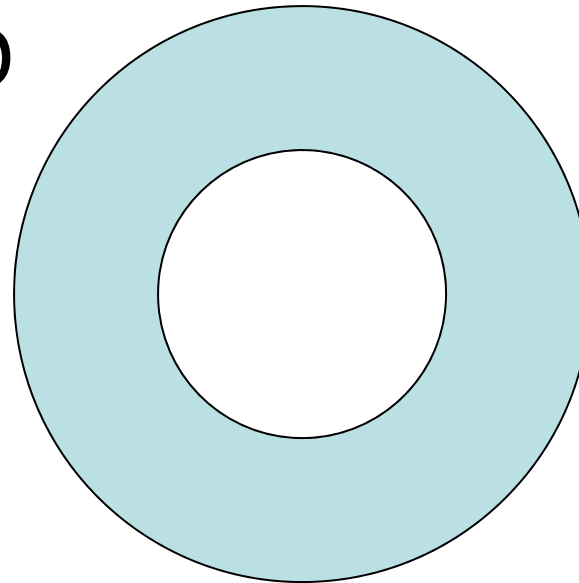
Federal Energy Regulatory Commission Division of Dam Safety and Inspections



Elements of a Dam Safety Performance Monitoring Program

STID

PFMA



Part12D/Annual Inspections

DSSMP



Federal Energy Regulatory Commission Division of Dam Safety and Inspections



STID

- An Executive Summary:
 - Project description
 - construction history
 - standard operating procedures
 - geology
 - hydrology and hydraulics
 - instrumentation and surveillance
 - stability and stress analyses
- Complete PFMA Report
- DSSMP/DSSMR (Section 7)



- Sufficient to understand design, construction, and current engineering analyses
- Not everything ever done



Federal Energy Regulatory Commission Division of Dam Safety and Inspections



Potential Failure Mode Analysis

- Potential failure modes for each structure.
Events leading to the failure are outlined.
Practicality of the failure event is assessed
and categorized
- Adverse (more likely) and Favorable (less likely)
factors
- Additional Monitoring or Performance Related Items
Discussed (Other Considerations)
- Major Findings and Understandings
- Risk Reduction Measures



Federal Energy Regulatory Commission Division of Dam Safety and Inspections



PFMA Focus Points

- 1. At PFMA reviews, Brainstorm – Identify All PFM's 1st**
- 2. Well defined PFM's (specific load case, location, etc.)**
- 3. Instrumentation\Monitoring appropriate to the PFM Category**
- 4. Existing instrumentation doesn't decide PFM Category**

Category should drive instrumentation program

- 5. Not every instrument needs a PFM**



Federal Energy Regulatory Commission Division of Dam Safety and Inspections



Potential Failure Mode Description

- **Step-by-step progression**
- **Verbal description enabling someone to visualize the progression from initiation to failure**
- **A process, where if one step does not occur, there is no uncontrolled release of water.**





Federal Energy Regulatory Commission Division of Dam Safety and Inspections



Potential Failure Mode Description

initiation-progression-failure...

- At the normal reservoir elevation of 2,348 feet, seepage begins to exit the left groin at elevation 2,290. The seepage increases until it begins to erode soil from the downstream face of the embankment. Backward erosion continues between the abutment and foundation soils and a roof begins to form allowing a pipe to develop. The pipe progresses until reaching the reservoir allowing the full reservoir head to begin flowing through the developed pipe. The pipe enlarges to the point where the embankment collapses into the pipe allowing the embankment to breach resulting in a catastrophic release of the reservoir.



Federal Energy Regulatory Commission Division of Dam Safety and Inspections



Potential Failure Mode Description

- **PFM Frequently Developed:**
 - Sliding of the concrete dam on the foundation.
- **More Appropriate PFM:**
 - During a period of normal high reservoir level at elevation 1,155 feet, and a continuing increase in uplift pressure on the shale layer slide plane, or a decrease in shearing resistance due to gradual creep on the slide plane, sliding of the buttresses initiates. Major differential movement between two buttresses takes place causing the deck slabs to become unseated from their simply supported condition on the corbels. Two bays quickly fail followed by the failure of adjacent buttresses due to lateral water load resulting in an uncontrolled release of the reservoir.
 - Is this a good PFM?



Federal Energy Regulatory Commission Division of Dam Safety and Inspections



Potential Failure Mode Description

This are actually two separate and distinct PFMs...

- **PFM 1:**

- During a period of normal high reservoir level at elevation 1,155 feet and ***a continuing increase in uplift pressure on the shale layer slide plane*** initiates sliding of the buttresses. Major differential movement between two buttresses takes place causing the deck slabs to become unseated from their simply supported condition on the corbels. Two bays quickly fail followed by the failure of adjacent buttresses due to lateral water load resulting in an uncontrolled release of the reservoir.
- **(Piezometers used to monitor uplift)**

- **PFM 2:**

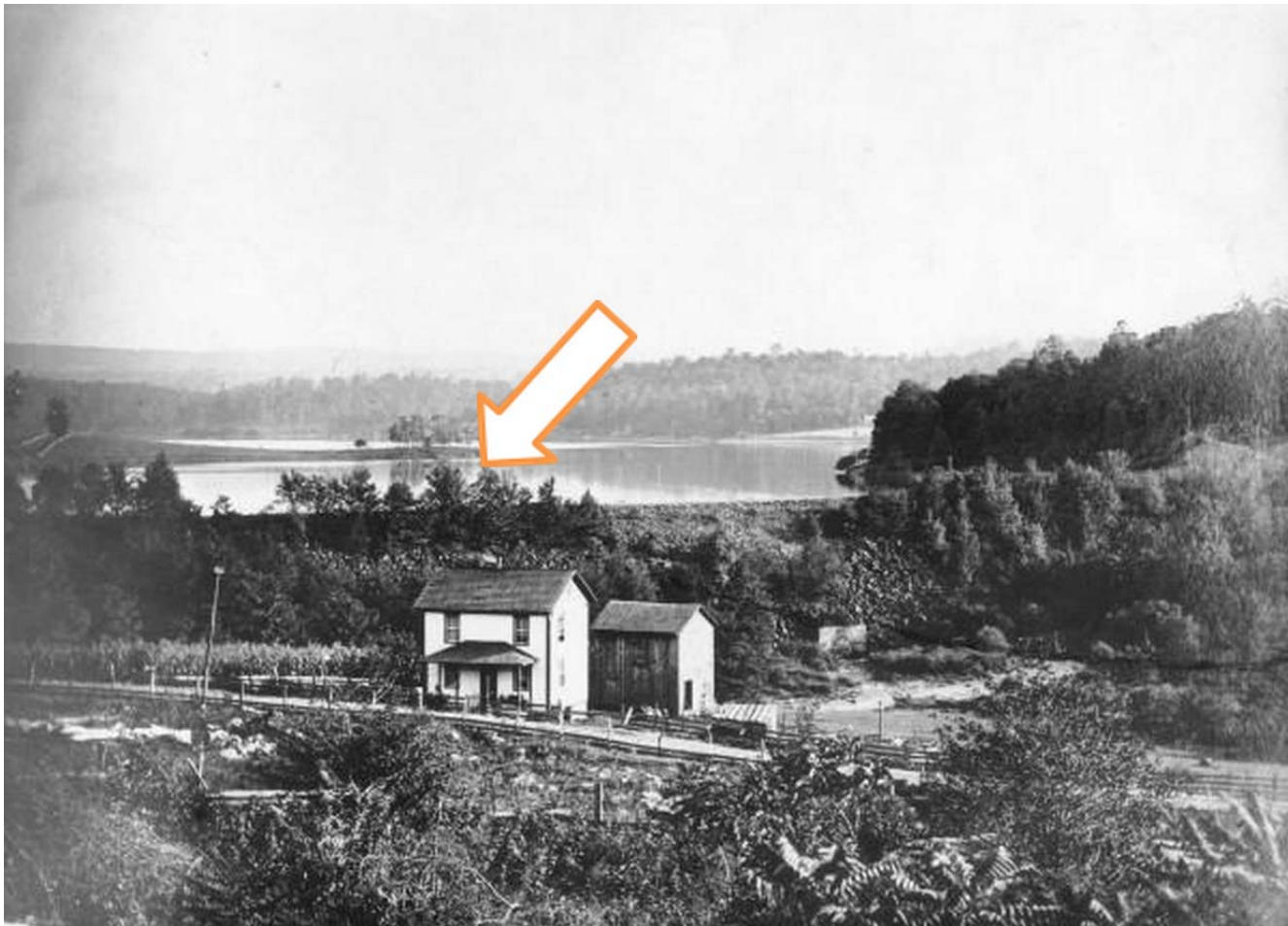
- During a period of normal high reservoir level at elevation 1,155 feet and ***a decrease in shearing resistance due to gradual creep on the slide plane initiates*** sliding of the buttresses. Major differential movement between two buttresses takes place causing the deck slabs to become unseated from their simply supported condition on the corbels. Two bays quickly fail followed by the failure of adjacent buttresses due to lateral water load resulting in an uncontrolled release of the reservoir. 19
- **(Survey monuments to monitor movement of dam)**



Federal Energy Regulatory Commission Division of Dam Safety and Inspections



Dam Quiz? No. 2





PFM Category I

- **Highlighted Potential Failure Modes** - 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*.
- **Surveillance and Monitoring Plan Required**



PFM Category II

- **Potential Failure Modes Considered but not Highlighted** - These are judged to be of *lesser significance and likelihood (than Cat I)*. 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.
- **Surveillance and Monitoring Plan Recommended**
- **If no plan, IC must explain why not warranted**



PFM Category III

- **More Information or Analyses are Needed in order to Classify.** 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.
- **Surveillance and Monitoring Plan Recommended**
- **If no plan, IC must explain why not warranted**



PFM Category IV

- **Potential Failure Mode Ruled Out** 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* a possibility as to be non-credible or not reasonable to postulate.



Federal Energy Regulatory Commission Division of Dam Safety and Inspections



PFM Categories - Review

“Additional Monitoring or Performance Related Items Discussed”

- ***Sometimes an item or issue brought up relates to dam safety, surveillance and monitoring or is of general concern but is recognized by all as something that does not or would not result in failure of the dam or other water retaining structure at the project and is thus not a candidate potential failure mode. However, such items still need to be included in the documentation to illustrate that they were identified, considered and were left to be addressed (potential identification of action) by the Part 12D consultant and or the owner. Such items are referred to as “Additional Monitoring or Performance Related Items Discussed” and are to be included in the report in a section under that heading.***



Federal Energy Regulatory Commission Division of Dam Safety and Inspections



PFMA – Risk Reduction Measures

Measures to lessen the likelihood of the PFM from developing:

- **Actions**

- Lower the reservoir?
- Minor modification?
- Major modification?
- Install more instrumentation?
- Automation? – with caution and a good understanding

- **Monitoring**

- More frequent
- Enhance monitoring by automation or adding vertical monitoring to concrete dam survey monuments.



**Federal Energy Regulatory Commission
Division of Dam Safety and Inspections**



Dam Safety Surveillance and Monitoring Plan.



Federal Energy Regulatory Commission Division of Dam Safety and Inspections



DSPMP - Background

- The Dam Safety Performance Monitoring Program (DSPMP) is an initiative that was developed by a team of FERC staff, licensees and consultants to address long term monitoring of dams in order to assure their continued safe and reliable operation.



Federal Energy Regulatory Commission Division of Dam Safety and Inspections



DSSMP

- The stability and integrity of a dam is assessed through observations and evaluation of instrument data and visual inspections relative to the expected physical appearance and design assumptions.



Federal Energy Regulatory Commission Division of Dam Safety and Inspections



DSSMP – Section 7 STID

1. Dam Safety Surveillance Program - Visual Inspection Plan
2. Instrumentation Monitoring Program
3. Potential Failure Modes

Appendix A - Drawings

Appendix B – Instrumentation Details

Appendix C – Inspection Forms



Federal Energy Regulatory Commission Division of Dam Safety and Inspections



DSSMP

- Visual observation at regular intervals
- Visual observations are judgmental rather than quantifiable.

“An instrument too often overlooked in our technical world is a human eye connected to the brain of an intelligent human being.”

Ralph Peck



Federal Energy Regulatory Commission Division of Dam Safety and Inspections



Consider for the DSSMP

- Outline the **physical** observations required. Surveillance is observation.
- **Simply list what an observer should be looking for and documenting.**
 - The good and the bad.



Federal Energy Regulatory Commission Division of Dam Safety and Inspections



Example Observations

- the appearance of the dam; is there any subsidence of a portion of the crest or is the crest level,
- the upstream/downstream alignment evaluated by any cracks in paving, the deflection or tilt of a fence, lightpost or any physical feature on the dam,
- the appearance and documentation of wet spots,
- the accumulation or lack thereof of sediment in a weir, drain or ditch;
- milky or clear flow in a drain or weir...etc.



Federal Energy Regulatory Commission Division of Dam Safety and Inspections



Dam Quiz? No. 3





DSSMP

- The DSSMP must address the instrumentation installed or suggested for each Category I-III failure mode
- Discuss any Category II Potential Failure Mode where the IC determines that instrumentation is not warranted
- The IC may recommend instrumentation and monitoring of a Category III potential failure mode in-lieu of further study if further studies to define the failure mode are unnecessary
- General Health Monitoring Instrumentation



Federal Energy Regulatory Commission Division of Dam Safety and Inspections



The DSSMP must include:

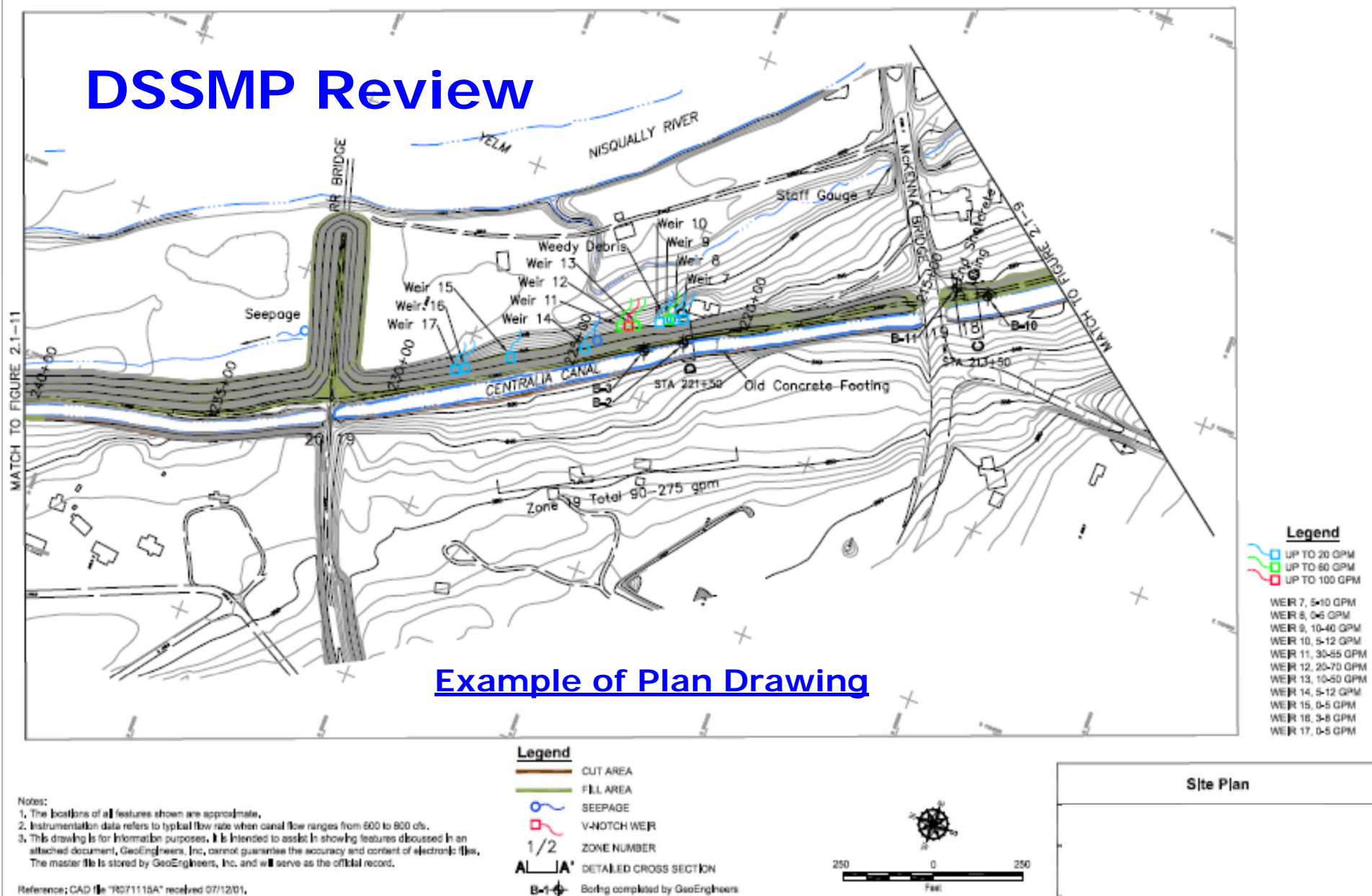
- Plan view of the instrument locations,
- Typical cross-sections of the various instruments,
- the details of the types of instrumentation,
- details of the instrument installation,
- General maintenance of the instruments
- the frequency of measurements,



Federal Energy Regulatory Commission Division of Dam Safety and Inspections



DSSMP Review





Federal Energy Regulatory Commission Division of Dam Safety and Inspections



The DSSMP must include:

- the frequency of calibration of the readout instruments
- action and/or threshold limits for each instrument
- requirement to record reservoir levels
- requirement to record climatic conditions, rainfall, snowfall, possibly snowmelt
- Training frequency for personnel



Federal Energy Regulatory Commission Division of Dam Safety and Inspections



Dam Quiz? No. 4





Federal Energy Regulatory Commission Division of Dam Safety and Inspections



DSSMR

Dam Safety Surveillance and Monitoring Report (DSSMR):

The DSSMR is a separate stand-alone periodic report that presents, evaluates, interprets, and provides findings on the overall performance of the dam.



Federal Energy Regulatory Commission Division of Dam Safety and Inspections



Dam 1





Federal Energy Regulatory Commission Division of Dam Safety and Inspections



DSSMR Review

- DSSMR is: An assessment/evaluation of the data and visual observations as they relate to the identified failure modes, using instrumentation plots and visual observation forms to support, or prove, the evaluation. The DSSMR should evaluate the DSSMP to insure sure it is adequately monitoring project structures based on most up-to-date information.



Federal Energy Regulatory Commission Division of Dam Safety and Inspections



I. Findings

This section should contain a summary of significant findings, conclusions, actions, changes or recommendations for the subject year or review period.

- State if the dam is performing adequately based on visual inspections and instrumentation.
- Discuss whether adverse findings are confirmed by instruments and/or visual monitoring
- State if DSSMP is appropriated for the identified PFM's. If not recommendations for improvement should be made.



Federal Energy Regulatory Commission Division of Dam Safety and Inspections



I. Findings (cont.)

- Address maintenance or actions proposed or completed relating to addressing DSSMR concerns.
- Discuss actions requiring future remediation.
- Discuss any changes in reading procedures and frequencies, or overall instrumentation program which will require DSSMP update.
- Recommendations for additional instruments or to abandon instruments.
- Recommendations to address additional PFMs that may be identified.



Federal Energy Regulatory Commission Division of Dam Safety and Inspections

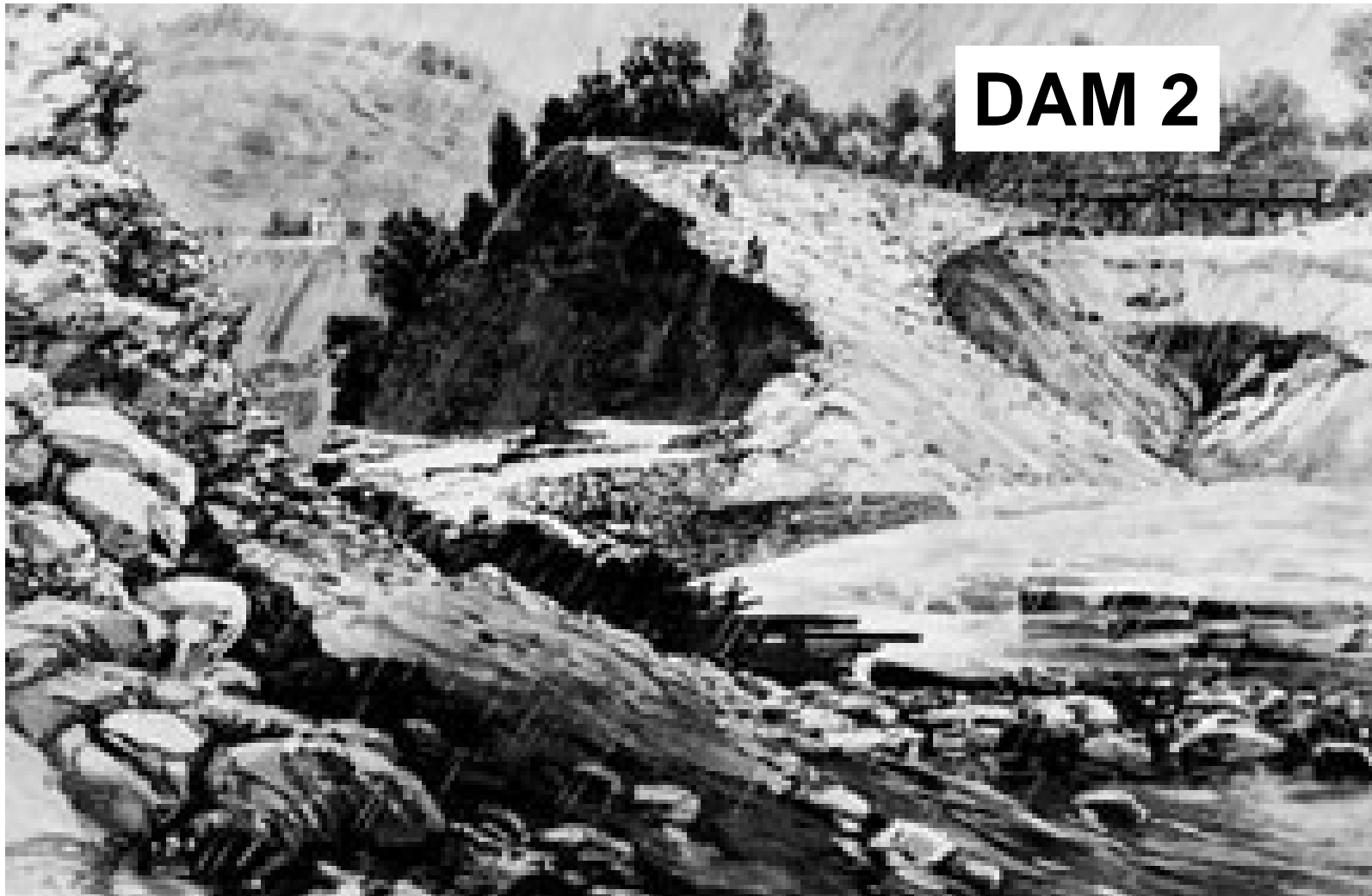


Examples of Inadequate Engineering Evaluations

- No Evaluation at all.
- Everything looks good.
- No unusual conditions were observed during inspections and no unusual instrumentation readings occurred.
- Instrumentation readings during the reporting period have been relatively constant with little variation. There have been no signs of instability during inspections.
- The instrumentation readings are all within historical trends.



Federal Energy Regulatory Commission Division of Dam Safety and Inspections



DAM 2

A contemporary illustration of the broken South Fork Dam
from Harper's Weekly.



Federal Energy Regulatory Commission Division of Dam Safety and Inspections



Example of Acceptable Engineering Evaluations

Based on visual observations and weir readings PFM #1 “loss of stability of a arch buttress due to piping along toe” does not appear to be active. The leakage along the toe does not appear to negatively impact the stability of the structure at this time.

The multiple arch buttress is founded on rock. There has been no apparent movement of material observed during readings of the leakage. The flows should continue to be monitored and be compared to historic readings. A trend of increasing flow in corresponding seasons of the year or a general overall increase may cause reason for further investigation or action.

Possibly threshold alert levels could be developed for these cases.



Federal Energy Regulatory Commission Division of Dam Safety and Inspections



II. Field Observations

This section should contain a summary of dam safety surveillance and monitoring items detected during inspections performed by plant personnel, staff inspectors or engineers, FERC engineers, state dam safety officials or special inspections (divers inspections, penstock inspection, etc.).



Federal Energy Regulatory Commission Division of Dam Safety and Inspections



III. Instrumentation Evaluation

- This section should include an evaluation of active instrumentation supported by sound engineering judgment.
- The evaluation should include a statement that the data shown by each instrument or each group of instruments is consistent with reasonable design assumptions.
- Or, if not, list the instruments that are inconsistent, why actual performance is not consistent with design assumptions, and the actions required to investigate or an explanation to accept the inconsistency.
- Any phenomenon that could influence the instrument readings (water temp, precipitation, ongoing construction, etc.) should be discussed as well.



Federal Energy Regulatory Commission Division of Dam Safety and Inspections



Example of Poor Instrumentation Evaluation

All instrumentation readings were within historical norms

Example of Acceptable Instrumentation Evaluation

The piezometer readings appear to be within acceptable limits based on the assumptions used in the stability analysis. The stability analysis assumed a uniform uplift pressure of 16.2 feet along the base of the buttress walls (elevation of base of buttress = 468.8 feet, uplift at elevation 485 feet). This value was evaluated due to a maximum elevation from the possible backwater effect at the toe of the multiple arch spillway from the downstream reservoir.



Federal Energy Regulatory Commission Division of Dam Safety and Inspections





Federal Energy Regulatory Commission Division of Dam Safety and Inspections



IV. DSSMP/DSSMR Changes

This section should discuss any changes that are recommended for the DSSMP including recommendations from the licensee, FERC, other agencies, or an independent consultant.

If no changes are necessary it should state so.



Federal Energy Regulatory Commission Division of Dam Safety and Inspections



V. Certification

Signature page including who prepared the report. A professional engineers stamp is recommended but not required. The qualifications of the reviewer should be included. The certification should identify the date or revision of the DSSMR guidelines that was used for the assembly of the report.



Federal Energy Regulatory Commission Division of Dam Safety and Inspections



DSSMR Appendix

Appendix A Significant Inspection Forms or Reports:

- This should contain inspection forms or reports that relate to the current findings in the DSSMR.
- These forms should include enough detail by structure to document site specific conditions as found during the inspection.
- Only forms or reports with significant findings should be submitted to reduce bulk of the DSSMR.
- Documentation of inspections and readings taken after a major occurrence (significant flood, earthquake) should always be included.



Federal Energy Regulatory Commission Division of Dam Safety and Inspections



DSSMR Appendix

Appendix B Supporting Drawings:

- The figures and other content of the appendices included in the DSSMR should be adequate to support the evaluations, findings and conclusions found in the report.
- Drawings and figures found in the DSSMP only need to be reproduced in the DSSMR to illustrate specific points or features of interest relating to the current DSSMR. At minimum drawings showing the location of the instruments should be included.
- Any drawings or figures included in the DSSMR should be of good quality and easy to read.



Federal Energy Regulatory Commission Division of Dam Safety and Inspections



DSSMR Appendix

Appendix C Instrumentation Plots:

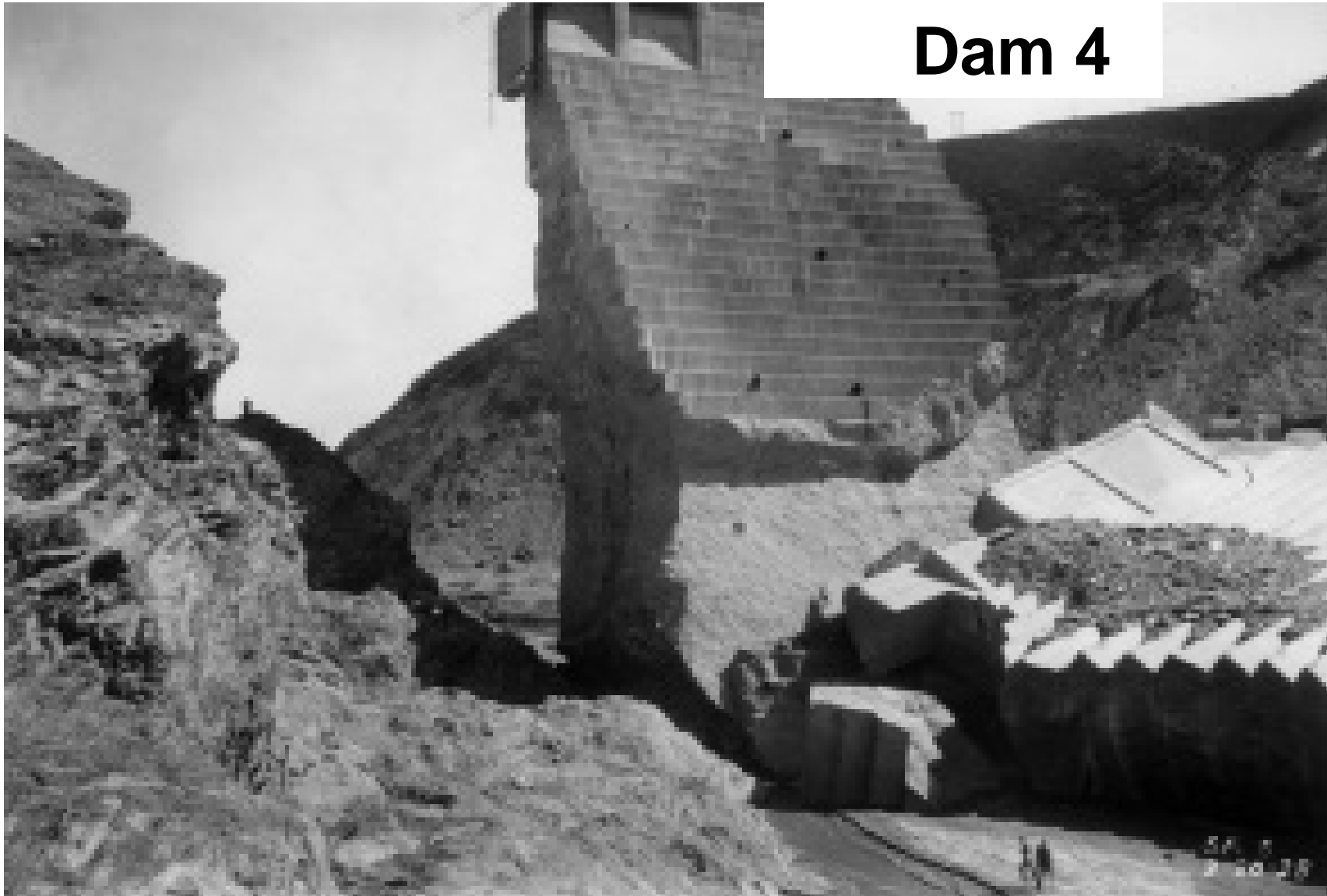
- Appendix C should include data plots of all pertinent instrumentations if applicable.
- There are generally four types of plots that can be considered;
 - Time versus Reading Plots
 - Cross Section Plots
 - Correlation Plots
 - Special Plots



Federal Energy Regulatory Commission Division of Dam Safety and Inspections



Dam 4





Federal Energy Regulatory Commission Division of Dam Safety and Inspections



Summary

- Simply because you do not have evidence that something exists does not mean that you have evidence that it doesn't exist.

Donald Rumsfeld

- The purpose of instrumentation and monitoring is to help quantify behavior and provide data to 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.