Reviewing and Revising the PFMA Report

The FERC Dam Safety Program is developing a Risk-Informed Decision-Making Program with initial implementation scheduled for 2014. A key component of risk-informed decision-making is a well done Potential Failure Mode Analysis (PFMA) with fully developed and described potential failure modes (PFMs). Without thoroughly developed PFM descriptions, from initiation through progression to failure, the probability of failure, and therefore the risk, cannot be adequately understood. In addition, as lessons from dam safety incidents are shared, the dam safety community increases its understanding of the potential failure modes that may be associated with a particular dam.

A recently completed review of PFMs developed under the FERC's PFMA process, found many to be inadequately developed (i.e. "Stability failure under any loading condition", or simply "Seiche"). Inadequate PFM descriptions do not provide the information necessary to adequately implement a dam safety surveillance and monitoring program, or adequately assess the risk at a dam. All PFMs should be fully developed and describe the complete potential failure sequence. This starts with the initial condition(s) (i.e. loadings, reservoir level, structural condition of the component(s) involved in the failure mode, etc.) at the initiation of the failure mode; the steps necessary for the failure to continue and progress (including location, path, other events during the progression that impact the progress of the failure mode being studied, etc.); and finally, the failure mode's impact on the particular structure (fast failure, slow failure, full breach, partial breach, etc.) and how would the reservoir be released. This process is shown visually in Figures 1 and 2.

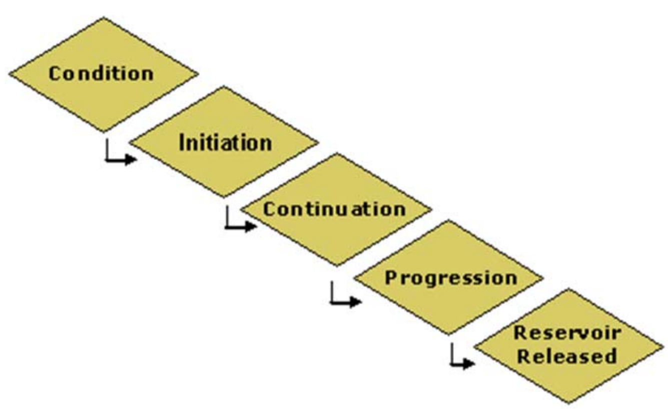


Figure 1 – Steps in the Description of a Potential Failure Mode

↳Reservoir at or above threshold level
↳Initiation – Erosion starts
↳Continuation – Unfiltered or inadequately filtered exit exists
↳Progression – Roof forms to support a pipe
↳Progression – Upstream zone fails to fill crack
↳Progression – Upstream zone or constriction fails to limit flows
↳Intervention fails to prevent “break-through”
↳Dam breaches

Figure 2 - Typical Internal Erosion PFM

Each step of a potential failure mode has a probability of occurrence. If it is determined that one of these steps is physically impossible, then the PFM is not credible. If the probability of any one of the events is extremely remote, then the PFM has an overall remote likelihood. However, when developing the full failure mode, a number of events may seem likely, and the PFM becomes credible taking on new significance. Without fully developing the PFM, the full credibility of the potential failure mode cannot be fully understood.

PFMs that are judged to be so unlikely as to be not credible should have either a written discussion of why the loading or condition is so improbable (i.e. meteor hitting the dam) or the failure mode should be developed to a point where continuation/progression process is physically impossible. The PFMA report should also clearly describe why a PFM was determined to be physically impossible to continue to failure.

Chapter 14 of the Engineering Guidelines states the PFMA 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 ...” The PFMAs should be reviewed during every Part12D inspection by a team including, at a minimum, the Independent Consultant, the owner’s chief dam safety engineer, a representative of the owner’s operating staff, and the FERC engineer. Prior to the Part 12D field inspection, the parties should review the existing PFMA report to determine if there are deficiencies in the PFM descriptions or if there are potential failure modes that were not included in the original PFMA report that should be developed during the review process. These new PFMs could be based on either new information that has come to light, changes observed in the project. or changes in the operation of the project. The parties should discuss the need for a supplemental PFMA session and if such a session is warranted, sufficient time should be allotted for the supplemental PFMA during the Part12D inspection. In the event that the original PFMA report requires an extensive amount of revision, it should be discussed with the FERC engineer whether it would be warranted to re-write the entire PFMA report and attach the original report as an appendix rather than add the PFMA review as a supplement.

In the interim between the Part 12D inspections, if new information is discovered or construction is planned that could affect dam safety, the owner and FERC staff would meet to complete a supplemental PFMA. The owner or its consultant should prepare a supplemental PFMA report.

The same level of rigor should be used to develop engineering information for supplemental PFMAs, as was used for the initial PFMA. This means that any studies or engineering analyses needed to inform the PFMA team should be completed prior to the supplemental PFMA and provided to the team. In addition, the designer of any changes to the dam should be present at the PFMA. If the supplemental PFMA results from a construction modification, members of the construction team present during the modification of the project should also be present during the PFMA.

Because the PFMA is a living document the STI should be revised accordingly to include a current and complete list of the PFMs, the original PFMA report, and any supplemental PFMA reports. One change from previous versions of the STI is the request to add a summary table to the beginning of the PFMA Section of the STI. The summary table should list all current PFMs and be included as the first page of the STI. The table does not require full and complete descriptions of each PFM, but should be a description sufficient to understand the general mechanism of the PFM. Appendix B contains an example PFM table.

All revised or supplemental PFMA reports should be distributed to the STI holders. The owner’s cover letter transmitting any revision to the PFMA report should discuss the reason for the revision and its potential impact on project safety. Those PFMA revisions would then be the foundation for the next Part 12D Independent Consultant inspection report 5 years later, or any intermediate PFMA revisions.

A presentation on how to complete PFMs is also posted on this website. Example PFMs are included in Appendix A to this document.

Two examples of potential failure mode descriptions are provided in Appendix A. The examples include an inadequate description from a PFMA session and how that same failure mode might look with a more complete description. The second example illustrates how the first attempt to rewrite a PFM actually resulted in the combination of two separate PFMs.

Appendix A

Internal Erosion PFM

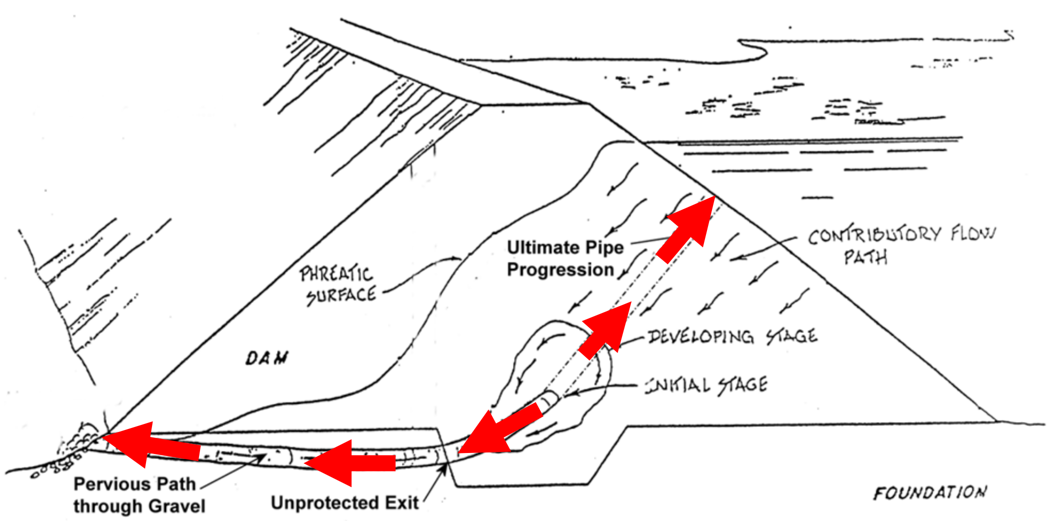
As initially described

Piping from the embankment into the foundation.

More Appropriate PFM:

When the reservoir is above elevation 5634 feet, internal erosion of the core initiates into the open-work gravel foundation at the interface of the foundation with the cutoff trench near Station 2+35, as a result of poor foundation treatment. Core material erodes into and through the foundation and exits at the toe of the dam through an unfiltered exit. Backward erosion occurs until a “pipe” forms through the core and continues upstream until reaching the reservoir. Seepage velocities increase, enlarging the pipe until a portion of the upstream face of the embankment collapses into the pipe, which continues to enlarge until the crest of the dam collapses, resulting in an uncontrolled release of the reservoir.

Note that the initiating circumstance (including reservoir elevation, location both vertically and horizontally in the dam, and cause of weakness in the dam of the initiator) is described. The continuation and progression is also described through failure. A sketch of the PFM is often a very useful way of helping to understand a complex PFM as shown below.



Sketch of Potential Failure Mode

Concrete Dam PFM:
As initially described:

Sliding of the concrete dam on the foundation.

Better PFM Description:

During normal maximum reservoir elevation and (1) a continuing increase in uplift pressure on the shale layer slide plane, or (2) 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.

However, this is actually two PFMs which should be described below:

Appropriate PFM:

PFM 1:

During normal maximum reservoir elevation, *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.

PFM 2:

During normal maximum reservoir elevation, *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.

Appendix B

Example PFM Summary Table

PFM SUMMARY TABLE*

PFM #	Potential Failure Mode Description
CATEGORY I	
1	Continued corrosion of the steel plug in the future penstock section of the dam results in a failure of the plug and uncontrolled release of the reservoir.
7	Internal erosion and piping of the core along the left wall of the spillway exits unfiltered into the downstream rockfill shell.
8	The left abutment experiences slope instability due to increased hydrostatic pressures resulting from clogging of the horizontal drains in the rock slope. A loss of support the slope provided to the concrete dam is removed, resulting in a stability failure of the concrete dam.
CATEGORY II	
2	Continued movement of the intake/powerhouse section results in the sliding failure of that section of the dam.
3	A large landslide into the reservoir creates a downstream wave that overtops the dam. This leads to sufficient erosion of the embankment dam, resulting in a breach of the dam and uncontrolled release of the reservoir.
4	Internal erosion and piping of the core along the poorly compacted left abutment contact with bedrock into the downstream rockfill.
CATEGORY III	
6	Liquefaction of the foundation of the right embankment during the design earthquake (PGA of 0.75g).
CATEGORY IV	
5	Sliding failure of the gravity section of the dam resulting from loading during the PMF event.
9	Liquefaction of the upstream face of the right embankment during the design earthquake (PGA of 0.75g).
10	Structural failure of the spillway piers due to cross-canyon loading during the design earthquake (PGA of 0.75g).
11	Overtopping failure of the right embankment during the PFM event.

* This table contains brief summary descriptions of the current PFMs. Refer to the PFMA report for the fully developed PFM descriptions.