*Federal Energy Regulatory Commission*

# Part 12D Refresher Training Potential Failure Modes Analysis (PFMA)

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# Potential Failure Modes Soapbox

- Potential Failure Modes (PFMs) are like Geotechnical Engineers, and…..
- We all get "**no respect!**"
- Without a thorough geotechnical investigation for a dam, your dam has a high risk of problems and possibly **failure** – unless you get lucky
- Without a detailed PFM, your risk-informed decision will be **flawed** – unless you get lucky

# Potential Failure Modes

- **Common Mistakes**
  - ***By far the biggest mistake made is rushing through a PFMA!***

# Potential Failure Modes

- **Other Common Mistakes**
  - Confusing "**valid**" PFM with a "**credible**" PFM
    - "Valid" can be "hand of God" or meteorite impact – something typically considered physically impossible or extremely remote
    - Credible is something physically possible, regardless of liklihood
  - **Do NOT** consider likely/unlikely factors when developing PFM
  - **Do NOT** say, it's always been this way so it must be ok!
  - Inadequate documentation of PFMA

# Potential Failure Modes

- Key Points to remember about PFMs and PFMAs
  - If it's not **documented**, it was not discussed.
  - Multiple PFMs can result by **changing a word** or two in a single PFM – but all must be separated into individual PFMs.
  - **Develop** each PFM to failure even if you realize that it's very remote while developing it.
  - Detailed **step-by-step** description of initiation to failure.
  - **Negative thinking** is encouraged to think of every possible way the dam can fail.

# Potential Failure Modes

- Key Points to remember about PFMs and PFMAs
  - To the FERC, a failure is an **uncontrolled release** of water.
  - Operation of an emergency spillway is not an uncontrolled release of water.
  - Is such a thing as a restricted uncontrolled release – outlet works, turbine, etc… Still considered a failure.

- Licensee Concerns
  - **Unacceptable performance** could be a failure to Licensee
  - A Licensee may consider the loss of a turbine a PFM even without a release of water. The FERC is concerned but it is not a dam safety concern

Example - Wanapum Dam

# Potential Failure Modes

- As mentioned, not all dams will undergo a formal risk analysis in the near future, (if ever) but…
  - PFMA review will be performed during **ALL** Part 12 inspections and should provide PFMs ready for use in a risk analysis.
  - PFMA is a crucial for evaluating **dam safety**.
  - You will likely **learn** a lot more about your dam.
  - Bound to be some **"Ah-ha"** moments and very possibly some **"#%*&?"** moments… especially for some CEOs once they understand the downstream **consequences** and **risk** posed by their dams!

# Potential Failure Modes

- **Communication to those unfamiliar**
  - They are ***POTENTIAL*** failure modes and not failure modes
    - Those unfamiliar with dam safety and the PFMA process may think the dam is going to fail in the procedure identified.

**PFMA *Review***

**vs**

***New* PFMA**

**and….**

**RIDM**

**vs**

**Part 12D**

# PFMA Review vs New PFMA

- **Why this is important?**
  - **Not** "just" another FERC initiative
  - The FERC found a large percentage of **inadequate** PFMs for both dam safety and RIDM.
  - Without good PFMs and a complete PFMA, dam safety issues could be **overlooked**.
  - Major improvement in **understanding** of the safety of your dam.

# PFMA Review vs New PFMA

Что , черт возьми RIDM???

There seems to be a lot of confusion regarding the application of RIDM to the PFMA review process!

# PFMA Review vs New PFMA

- **RIDM Confusion**
  - At this stage, RIDM ***does not impact*** your PFMA or project, ***HOWEVER***, a PFMA serves the future of RIDM!
  - ***Dam safety*** relies exclusively on a **complete PFMA**.
  - **RIDM** relies heavily upon a ***complete PFMA.***
  - Without **complete PFMs**, a PFMA ***does not serve*** the **dam safety** of your project appropriately.
  - Without ***complete PFMs***, a PFMA **does not serve** your **risk analysis**.

- Should a:

**PFMA Review < New PFMA**

or

**PFMA Review = New PFMA?**

# PFMA Review vs New PFMA

- **New or First-time PFMA**
  - Requires experts in all fields of study (structural, H&H, geotech, etc..), operators, and anyone with expertise about the project.
  - A facilitator experienced in facilitating PFMAs.

# PFMA Review vs New PFMA

- **PFMA Review – Evaluate existing PFMA**
  - Evaluate the adequacy of your **existing** PFMs?
  - Any **new** conditions observed?
  - Any **changes** in operational procedures?
  - Any new **documentation** discovered?
  - Have there been any **modifications** to the project?
  - **Summary**: any changes in operation, information, observations, etc… since original PFMA needs to be discussed during PFMA review.

# PFMA Review vs New PFMA

- **PFMA Review – Evaluate existing PFMA**
  - **May** require experts in all fields of study (structural, H&H, geotech, etc..), operators, etc… depending upon the quality of the initial PFMA.
  - **May** be conducted by the IC, unless extensive rework required and should be facilitated as a first-time PFMA.

# PFMA Review vs New PFMA

- **PFMA Review - Procedure**
  - Detailed review of **ALL existing** PFMs to determine if they are fully developed… ***including*** Category IV and "other considerations!"
    - If not fully developed, they must be developed into complete PFMs
  - Any PFM **not fully developed** must be refined
  - Review all "**other considerations**" taking any new information into consideration.
  - Review the **category** of each PFM.

# PFMA Review vs New PFMA

- **PFMA Review - Procedure**
  - If you find that your PFMA is:
    - poorly documented
    - requires extensive revisions
    - Requires the addition of numerous PFMs…..
  - You may need to consider writing an entirely new report!

# Conducting a New PFMA

# OR

# PFMA Review / Supplemental PFMA

# PFMA Preparation

- Supplemental PFMA may include:
  - a PFMA review
  - a construction PFMA
  - a new design PFMA

- A focused PFMA could focus only at a specific portion of the project, which should then be incorporated into the next PFMA review.

# PFMA Preparation

- A lot of similarities between both
- Do your homework
  - Review project information
  - Review existing PFMs
  - Do your own brainstorming for new PFMs prior to the actual PFMA team effort
  - Have documents available for reference at the PFMA

# Facilitating PFMA

# Facilitating a PFMA

- Multiple ways to perform a PFMA
  - Assign team homework to develop PFMs prior to PFMA and start by reviewing these PFMs
  - Jump in with both feet developing the first PFM that comes to mind
  - Brainstorm the entire project before fully developing any PFM

# Facilitating a PFMA

- Thank you for asking MY recommendation!
  - (One advantage of having a captive audience!)

- Brainstorming
  - Discuss entire project before heading into the weeds!

# PFMA Brainstorming

- Discuss one loading condition or one pathway at a time for each portion of the project and complete brainstorming before moving on.
  - Normal (static) loading
  - Seismic loading
  - Hydrologic loading
  - Internal erosion through embankment
  - Internal erosion through foundation
  - Internal erosion from embankment into foundation
  - Etc…

# PFMA Brainstorming

- For each loading condition discuss:
  - Original Design
  - Construction
  - Performance since construction
  - Focus on any problem areas, but…
    - Don’t get sidetracked away from looking at entire project

# PFM Categories

# PFM Categories - Review

- The FERC is trying to clarify the confusion surrounding PFM Categories.
  - Our intent is to get our nationwide program all on the same page!
- If you do not fully develop a PFM, you cannot categorize it.

# PFM Categories - Review

- Great confusion about categories
  - Do not consider risk when selecting categories
  - Do not confuse deterministic with probabilistic thinking
  - PFM is developed with understanding that each preceding event does occur.

- Remember “credible” vs “viable” PFM definition
  - Do NOT consider likelihood when developing PFM
  - DO consider likelihood of PFM happening when determining category

# PFM Categories - Review

- 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*.

# PFM Categories - Review

- Category I
- What it is!
  - **Highlighted PFM** that is ***critical to dam safety*** and requires frequent monitoring
    - Must be Included in Dam Safety Surveillance and Monitoring Plan (DSSMP)
    - Instrumentation may be limited to visual observation
- **What it is not!**
  - An **automatic** identification of a dam safety deficiency
  - An **automatic** requirement to spend $$$$$$$$ to mitigate a dam safety deficiency

# Category I – Example

- 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 embankment soils forming a roof that allows a pipe to develop through the embankment 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.

# Category I – Example

- Why is this a Category I? (Likely and Unlikely)
  - Seepage begins to exit the left abutment when the reservoir reaches elevation 2,348 feet.
  - There is evidence that seepage flows have resulted in the erosion of embankment soils.

- Risk Reduction Measures
  - Restrict reservoir to an elevation below 2,348 feet
  - Increase visual monitoring of left groin when reservoir reaches elevation 2,348 feet and above

# PFM Categories - Review

- 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.

# PFM Categories - Review

- Category II
- What it is!
  - PFM that is very **important to dam safety** to keep monitoring on a regular basis
    - Must be Included in Dam Safety Surveillance and Monitoring Plan (DSSMP)
    - Visual monitoring
    - Instrumentation
- **What it is not!**
  - A PFM that can be totally ignored in your DSSMP

# Category II – Example

- 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.

# Category II – Example

- You note that these are identical PFMs
- What is the difference?
  - **Category 1** because monitoring program notes seepage develops when the reservoir reaches elevation 2,348 vs **Category II** because no seepage ever noted in left groin, but data indicates a change in construction that causes some concern. You must *always monitor seepage at embankment dams*.
- Risk Reduction Measures
  - Increase frequency of visual monitoring of left groin when reservoir reaches elevation 2,348 feet

# PFM Categories - Review

- 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.

# PFM Categories - Review

- Category III
- What it is!
  - A PFM that you has **insufficient** information to classify at the time of the PFMA.
- **What it is not!**
  - A way to delay a decision about a possible dam safety issue.

# Category III – Example

- During a seismic event, the cross-canyon motions cause the spillway piers to fail allowing the spillway gates to become detached from the piers. The loss of the gates result in an uncontrolled release of water and loss of 60-percent of the reservoir volume.
  - Unknowns:
    - No design Peak Ground Accelerations developed for the project
    - No structural analysis of the spillway piers addressing cross-canyon shaking.

# Category III – Example

- Important note!
- The FERC will require a plan and schedule to address the missing information in any Category III PFM in order to make a final determination of the PFM category (I, II, or IV)

# PFM Categories - Review

- 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.

# PFM Categories - Review

- Category IV
- What it is!
  - The most **misinterpreted** category of PFM
  - The category that results in a lot of confusion and wasted discussion time
  - PFMs fully developed but found to be non-credible ***or*** physically impossible.
- **What it is not!**
  - A category to be confused with Category II
  - Does not require incorporation into the DSSMP
  - An appropriate category for any seepage PFM

# Category IV – Example

- During the PMF, flows of 235,590 cfs overtop the concrete gravity dam by four feet for 5 hours. The flows erode the bedrock at the right abutment resulting in the loss of support of the right abutment of the dam. The flood load causes the right side of the dam to slide downstream sufficiently to allow a catastrophic release of the reservoir.

# Category IV – Example

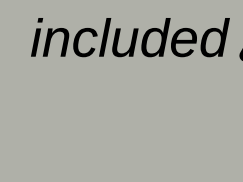
- Why is this a Category IV
  - The dam overtops for only 5 hours
  - A scour analysis of the bedrock indicates that it would not erode under the PMF overtopping conditions
  - The stability analysis indicates that the dam is stable with most of the bedrock gone.

- Risk Reduction Measures***
  - None

*** Note: if there are risk reduction measures it should not be a Category IV

# PFM Categories - Review

- "Other Considerations"
  - *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.*



Section Title in PFMA Report.

# PFM Categories - Review

- Other Considerations

- What it is!
  - **Documentation** of all brainstormed PFMs discussed but not fully developed.
  - PFMs **not fully developed** because they were determined by the team to be much less likely than other similar PFMs
  - PFMs that may or may not require incorporation into the DSSMP

# PFM Categories - Review

- Other Considerations

- What it is not!
  - A “catch all” category to put everything that you don’t want to develop into a full PFM
  - An automatic “out-of-sight out-of-mind” PFM with regards to your DSSMP

# Other Considerations – Example

- *Seepage from the left abutment into the embankment during normal reservoir conditions at elevation 2,348.*

- During the development of PFM #(on next slide), the team discussed the possibility of seepage from the abutment into the embankment. This PFM was ruled out from full development because the abutment is hard, lightly fractured/jointed bedrock that would not erode and provide full access to the reservoir. The team also concluded that seepage would either be filtered by the properly compacted filter or saturation of the downstream shell would not result in a slope failure sufficient to release the reservoir.

# Other Considerations – Example

- 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.

# Other Considerations – Example

- You note that these could be developed into near-identical PFMs
- What is the difference?
  - The team determined the most likely path was along the abutment/embankment contact and not into the abutment and warranted full development
- Risk Reduction Measures
  - Visually monitor the left groin for the development of seepage.

# Category – General Notes

- **IMPORTANT NOTE:**
  - **All internal erosion and piping PFMs should be included in your visual monitoring program regardless of classification. They could develop at any time and you must be diligent in monitoring for changes in seepage.**
  - **The IC or facilitator (Review vs new PFMA) must make the final determination of the Category and not simply list the votes of the PFMA Team.**

# PFM Categories - Review

- Miscellaneous considerations
  - No dual Categorization
    - PFMs should be a single Category since there are clear distinctions between each Category.
  - Preferred numbering
    - 1,2,3,4,5,etc…
  - Be clear when using possible confusing numbering
    - 1, 1A, 1B

# Risk Reduction Measures

# PFMA – Risk Reduction Measures

- Another critical part of the process
  - 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.

# Correlation of Instrumentation to PFMs ?

# PFMA – Instrumentation

- A recent FERC initiative required the submittal of a table in the Dam Safety Surveillance and Monitoring Report (DSSMR) that correlates instrumentation with PFM beginning with 2014 DSSMR submittals.

- Consider adding this discussion to the PFMA process to aid in the understanding of the PFMs.

# PFMA – Instrumentation Table

**NEWLY IDENTIFIED PFMs (Follow Procedure in Chapter 14, Section 14.3.6 for Updating PFM's)**

| PFM – Number/Title(s) | Monitoring Effort | Result |
|---|---|---|
| Sliding of the non-overflow under normal loading conditions (candidate PFM identified during evaluation of deformation survey results) | Deformation Surveys | Differential movement detected and further evaluation of stability is needed |
| | Daily operator inspections | New cracks found on 9/18 |
| | Monthly supervisor inspection | No adverse findings |
| | Annual engineer inspection | No adverse findings |
| Failure of Penstock No. 1 due to corrosion under normal loading (candidate PFM identified during review of STID) | Daily operator inspections | No visual changes to corrosion or leakage detected |
| | Monthly supervisor inspection | No visual changes to corrosion or leakage detected |
| | Annual engineer inspection | No visual changes to corrosion or leakage detected |
| | Ultrasonic thickness measurements | Section loss detected, see evaluation on page 19 |

**INSTRUMENTATION NOT ASSOCIATED WITH A PFM: (General Health of Dam)**

| Monitoring Effort | Result |
|---|---|
| PZ-5 | No adverse trends, no thresholds exceeded |
| Surveillance Camera at Weir | No visual changes or seepage with soil fines |
| Deformation Surveys | No adverse trends, no thresholds exceeded |
| Daily operator inspections | No adverse findings |
| Monthly supervisor inspection | No adverse findings |
| Annual engineer inspection | No adverse findings |

# What is an Appropriate Number of PFMs for a Dam?

# PFMA – Risk Reduction Measures

- What's the minimum number of PFMs that should be developed?
  - Answer:  As many as you need!
  - There should be a minimum of one fully developed PFM per loading condition and/or dam feature
    - Each type of internal erosion
    - Spillway structure/chute
    - Spillway gates
    - Concrete structures
    - Seismicity
    - Flooding

But as in all things FERC, there are always exceptions.  Use good judgement!

# Examples of fully developed Potential Failure Modes

# Potential Failure Mode Description

- Step-by-step progression
- “Connect-the-dots” process
- Verbal description enabling someone to visualize the progression from initiation to failure
- A process, where if one step does not occur, neither with an uncontrolled release of water.

# Potential Failure Mode Description

- **Internal Erosion process, but similar for all PFMs**

↳Reservoir loading condition

↳Flaw exists – Continuous crack, high permeability zone, etc.

↳Initiation – Particle detachment (erosion starts)

↳Continuation – Unfiltered or inadequately filtered exit exists

↳Progression – Continuous stable roof and/or sidewalls

↳Progression – Constriction or upstream zone fails to limit flows

↳Progression – No self-healing by upstream zone

↳Unsuccessful detection and intervention

↳ Dam breaches (uncontrolled release of reservoir)

# Potential Failure Mode Description

- Remember this example?  Paragraph format:
- 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.

# Potential Failure Mode Description

- Bullet example (often easier to create an event tree)

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

# Potential Failure Mode Description

- **<u>PFM Frequently Developed:</u>**
  - Sliding of the concrete dam on the foundation.
- **<u>More Appropriate PFM:</u>**
  - 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.
  - Or is this actually correct?

# Potential Failure Mode Description

- This are actually two separate and distinct PFMs – Do not combine different loading conditions or failure mechanisms into one PFM.

# Potential Failure Mode Description

- 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.

    (Survey monuments to monitor movement of dam)

# Potential Failure Mode Description

- **PFM Frequently Developed:**
  - Dam overtopping due to gate operation failure.
- **More Appropriate PFM:**
  - During a 250-year flood, flows in excess of 12,000 cfs are requited to pass through a remotely controlled gate. The limit switch on the automated gate fails to prevent releasing flows that will wash out the only access road fails (occurred in 1994) due to a loss in communications equipment. The gate fully opens wiping out the access road. An operator is deployed to the site, but cannot make it to the dam. The release capacity of the single automated gate is insufficient and the dam overtops, eroding the embankment resulting in an uncontrolled release of the reservoir.

# PFMA Report

# Potential Failure Mode Report

- Original PFMA Report should never be altered
- **PFM Review:**
  - Appendix attached to original PFMA Report
- **New PFM Report**
  - If the existing PFMA Report is found to require a very significant rewrite, produce a new report and attach the original report as an Appendix to the new report.

# PFMA – Instrumentation

**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.

# Potential Failure Modes

- More detailed PFM presentation and information on our web site

**FERC.gov**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# Part 12D Refresher Training
# Potential Failure Modes Analysis (PFMA)
# Questions? Discussion?