Specialty Geotechnical Workshop for Dam + Levee Investigations + Modifications

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Dam and Levee Safety Risk During Remedial Construction

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Acknowledgment

Most of the content in this presentation is from a Corps of Engineers update to chapter H-3 Construction Risk of the Best Practices for Dam and Levee Risk Assessment that I authored prior to retiring from the Corp.

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Outline

- Key Concepts
- Conditions That Can Lead to Increased Risk
- Constructability Evaluation
- Mitigation of Risk
- Decision Maker Involvement
- Cofferdams
- Case Histories

Key Concepts

- Construction Risk: Risk to public during construction
- Decision makers need to understand construction risks and cost trade-offs.
- Do no harm.

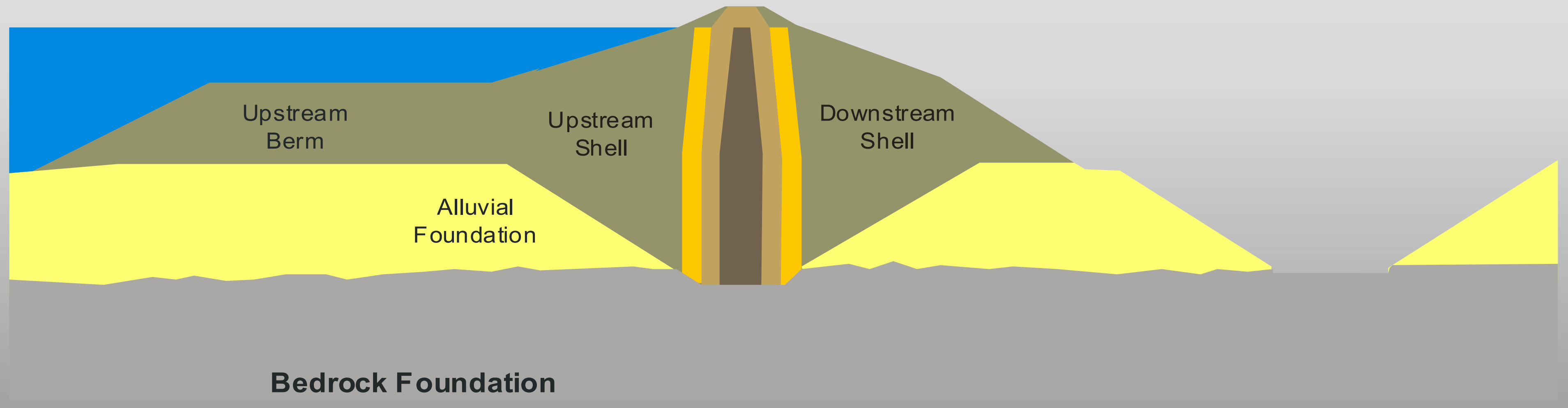
Conditions That Can Lead to Increased Risks During Construction

Excavations that lower the crest of the dam or levee can increase the risk of flood overtopping.

Degraded Levee for Cutoff Wall Construction

Conditions That Can Lead to Increased Risks During Construction

Excavations at the toe of a dam that increase its susceptibility to sliding instability.



Dam With A Toe Excavation

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Conditions That Can Lead to Increased Risks During Construction

Excavations that remove a portion of the downstream slope or foundation can lead to increased susceptibility to internal erosion

Excavation of a Ditch at the Toe of a Levee that led to Breach

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Conditions That Can Lead to Increased Risks During Construction

Rapid construction of embankments can increase likelihood of slope instability.

Fort Peck Dam (left) and Waco Dam (Right) Slides During Construction

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Conditions That Can Lead to Increased Risks During Construction

Inadequate cofferdams can lead to higher risk of flooding.

Auburn Dam Cofferdam Overtopping Failure

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Conditions That Can Lead to Increased Risks During Construction

Clogged bypass tunnels can increase the risk of flooding.

Landslide Blocking Bypass Tunnels Ituango Dam

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Conditions That Can Lead to Increased Risks During Construction

Spillway remediation can increase the chance for uncontrolled releases or overtopping.

Spillway Gate Repair Behind Temporary Bulkhead

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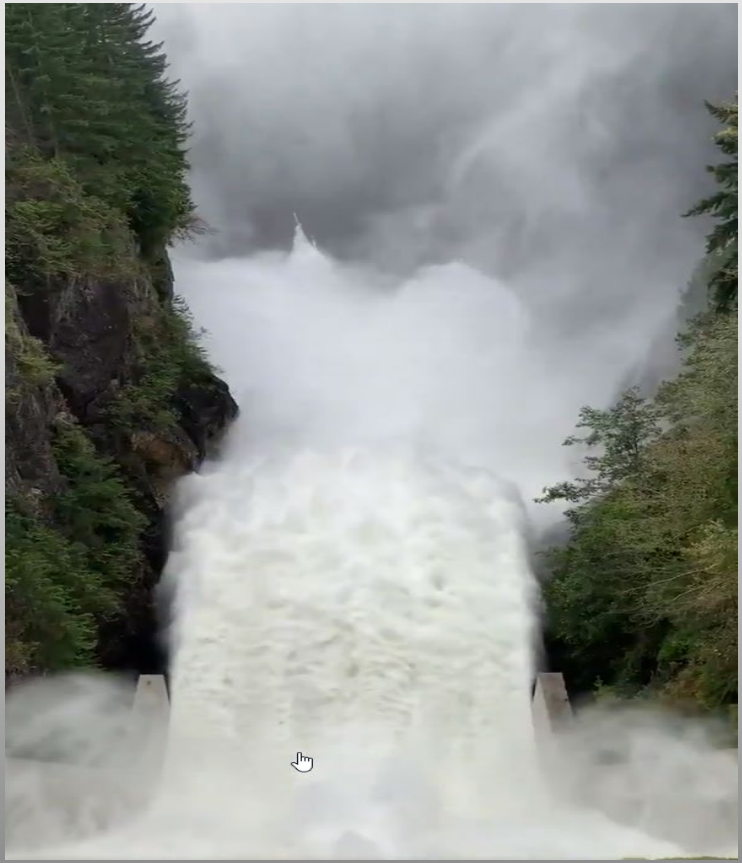
Conditions That Can Lead to Increased Risks During Construction

Gate repair can result in the inadvertent opening of gates.



Inadvertent Spillway Release During Repair Work

Conditions That Can Lead to Increased Risks During Construction

Temporary removal of flood protection (levee or floodwall) can expose the protected area to increased flood risk.

Levee Section Removed for Culvert Replacement

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Conditions That Can Lead to Increased Risks During Construction

Constructing remedial elements like grout curtains and cutoff walls adjacent to existing structures can lead to damage and potential initiation of internal erosion.

Bottom Outlet Tunnel Damaged by Grout Curtain

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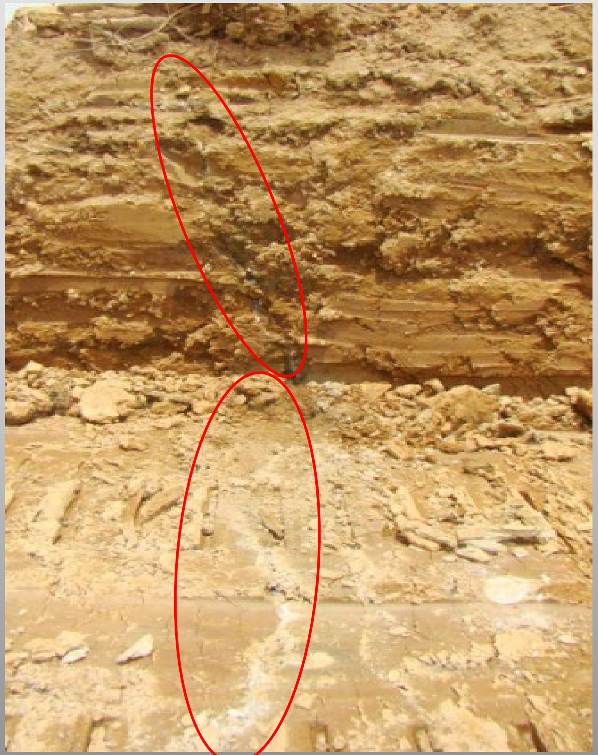
Conditions That Can Lead to Increased Risks During Construction

Drilling fluids and grouting pressures can cause hydraulic fracturing and ground displacement.



Grout Hydraulic Fracture

Crack in Dam Crest Related to Grouting

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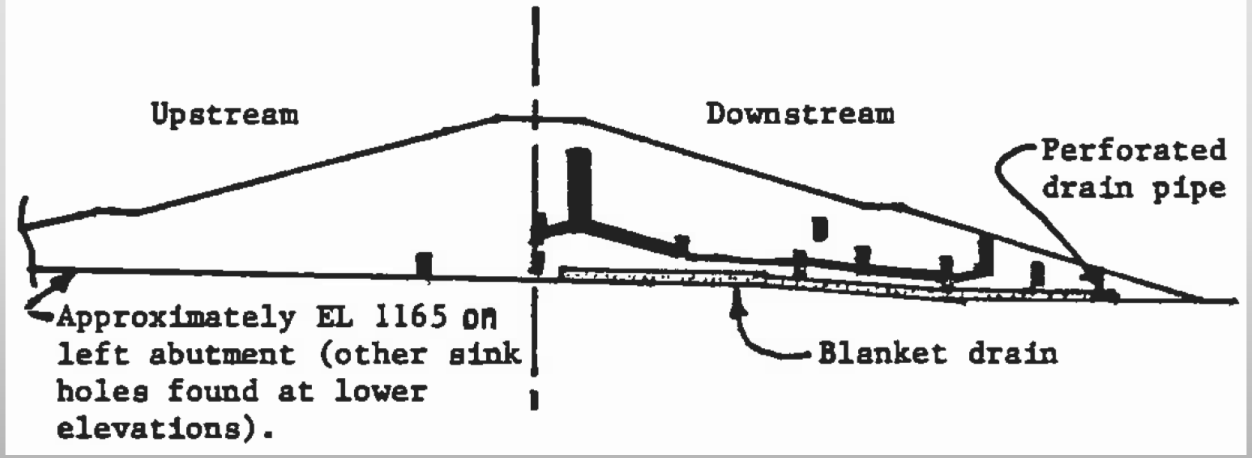
Conditions That Can Lead to Increased Risks During Construction

Uncontrolled drilling fluids or grouting activities have the potential to clog drainage systems.

Uncontrolled Grout Discharge

Conditions That Can Lead to Increased Risks During Construction

Improperly constructed filters or drains can potentially provide an unfiltered exit for seepage.



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Conditions That Can Lead to Increased Risks During Construction

Any other examples?

Constructability Evaluation

Planned Constructability Reviews

- Identify risk and methods for mitigation
- Mixed team of designers and construction personnel

Constructability Evaluation

- Performed in study phase and 65% design
- During design phase special techniques, scheduling, etc. can be developed to mitigate risk
- Risk can be qualitatively or quantitatively evaluated

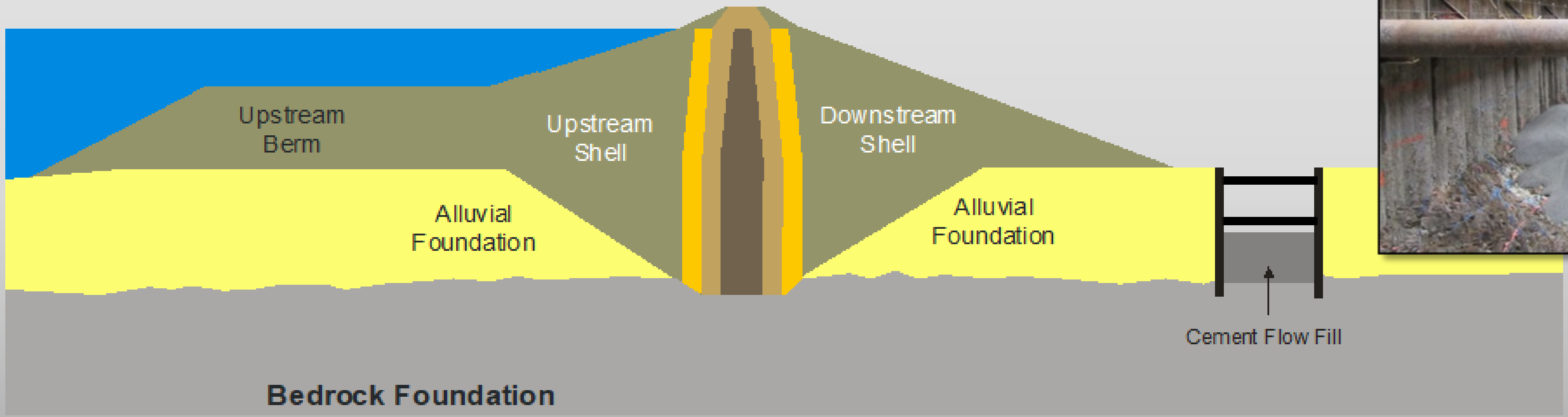
Mitigation of Risk

Develop a detailed sequence of work that minimizes the risk.

For example: A slope excavation can be sequenced to always be unloading the top of the slope instead of the bottom which may destabilize the slope.

Designers need to verify that specified sequences are being followed during construction.

Mitigation of Risk



Slope Instability Mitigated by Braced Excavation

The length and extent of open trench excavations can be limited to minimize prolonged exposure conditions

Mitigation of Risk

Robust cofferdams can reduce construction risk

Cofferdam for Folsom Spillway

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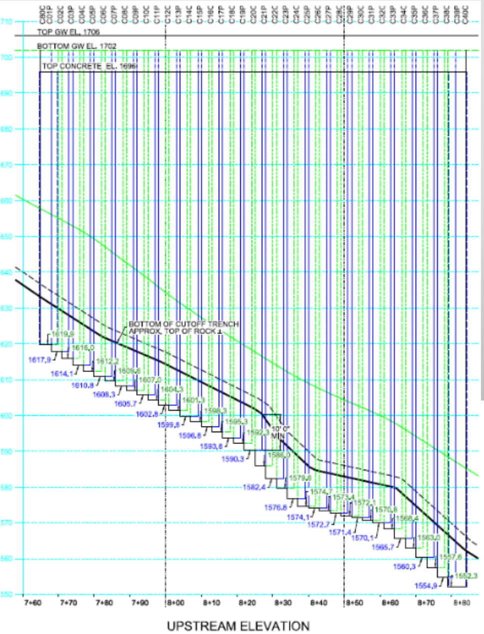
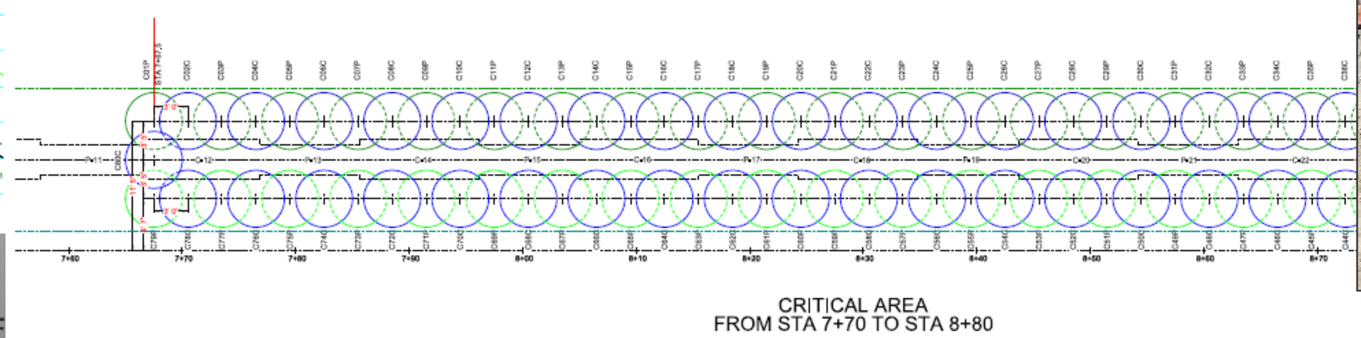
Mitigation of Risk

Special techniques can be required on portions of a project in order to mitigate risk.





Secant Pile Encasement Wall

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Mitigation of Risk

Special techniques can be required on portions of a project in order to mitigate risk.

Grouting Prior to Cutoff Wall Construction

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Mitigation of Risk

- Modify schedule to work during low water periods
- Restrict pool levels to reduce risk
- Increase shifts to shorten construction duration

Mitigation of Risk

Pool Restrictions

How can restricting the pool reduce the risk?

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Mitigation of Risk

How can restricting the pool reduce the risk?

- Reduce frequency of the load
- Reduce magnitude of the load and lower probability of failure
- Reduce potential consequences due to less water in a breach

Mitigation of Risk

Demonstration Sections

- Test Concepts and Procedures in Non-Critical Areas
- Evaluated Contractors Expertise
- Modify Processes

Decision Maker Involvement

- Critical to keep decision makers informed
- Designers must be able to clearly describe the risk.
- Key decisions are risk-cost-schedule tradeoffs
- Decision makers must be able to make good risk informed decisions

Cofferdams

- Cofferdams require the same risk considerations as the dam or levee
- Consequences need to be considered
- Will failure release water to the downstream PAR or just flood the work area?
- There is usually a cost vs risk tradeoff involved in cofferdam design.
- Decision makers should be involved in selecting the level of flood protection.

Cofferdams

- Risk need to be determined for overtopping and other failure modes.
- Cofferdams have also failed due to sliding instability and internal erosion.
- For enclosed cofferdams, the risk of breaching due to overtopping, can be mitigated with components to allow controlled flooding of the excavation area.

Cofferdams

Controlled Flooding of Cofferdam

Cofferdam Overtopping

Case History- Cofferdam for Outlet Works Replacement

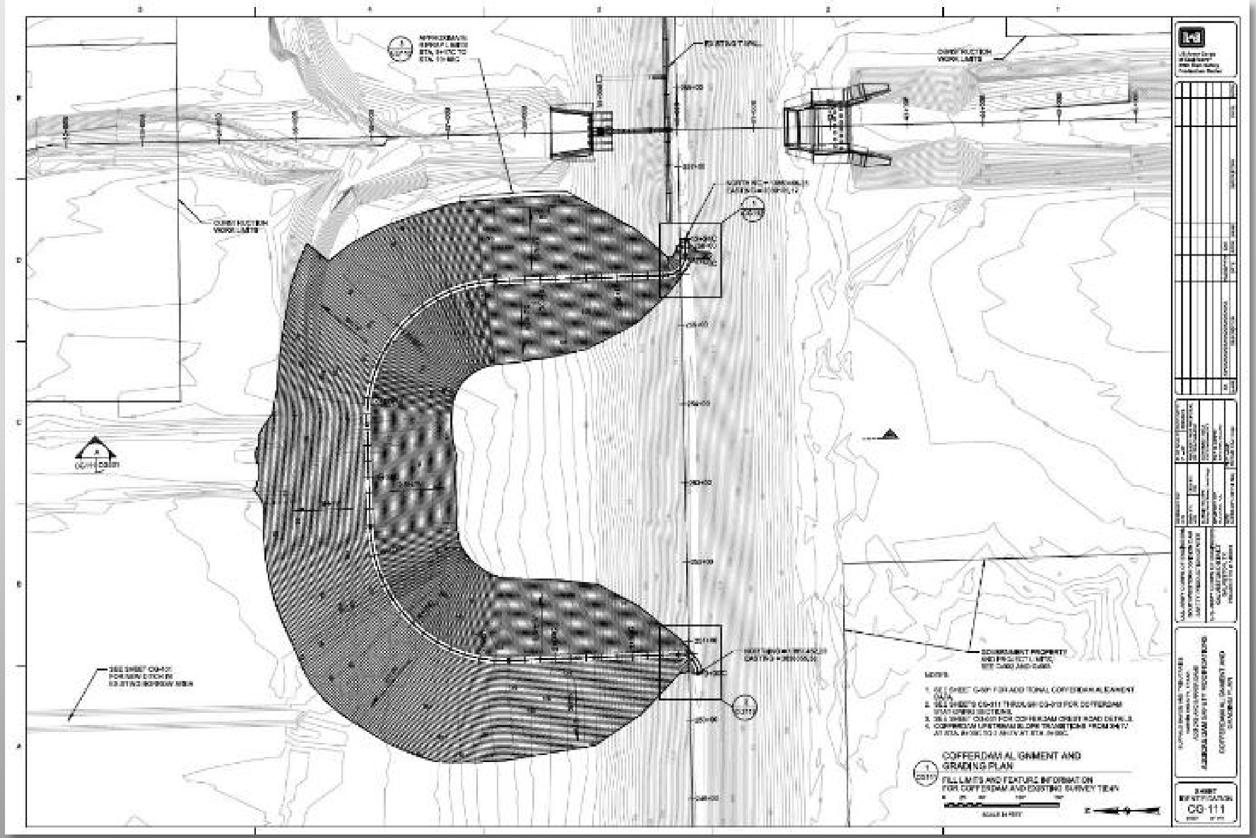
Importance of considering construction risk when determining the height of a cofferdam.

Cofferdam required to replace outlet works due to Internal Erosion along and into the conduit.

Outlet Works Prior to Replacement

Case History- Cofferdam for Outlet Works Replacement

Cofferdam protected the work area during construction and functioned as the dam during construction.



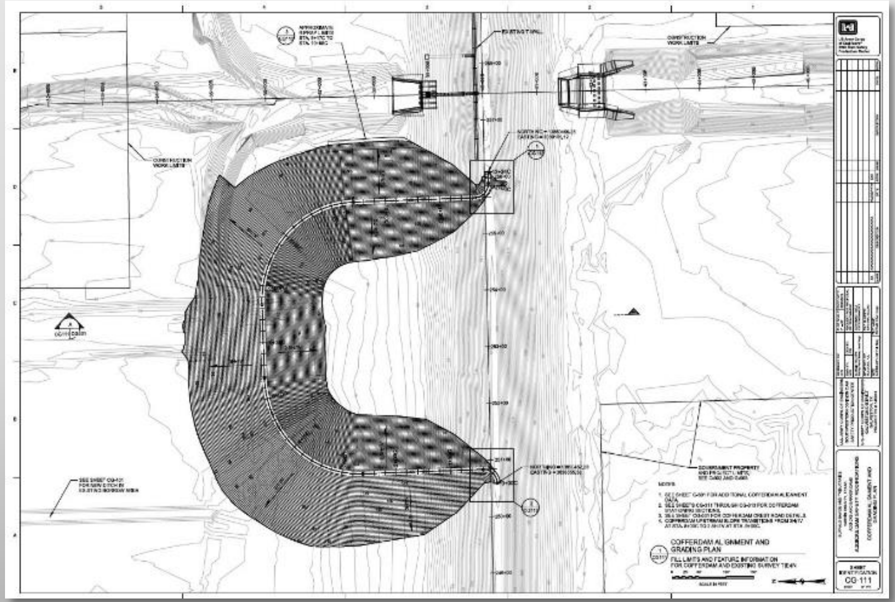
Cofferdam Layout

Case History- Cofferdam for Outlet Works Replacement

- Constructability review during the study phase recommended full height cofferdam

- VE Study recommended reducing the height of the cofferdam to save $1.3 M.

- With a PAR of 1.2 Million and potential economic losses of $60 Billion, decision makers did not approve the VE recommendation.



Cofferdam Layout

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Case History- Cofferdam for Outlet Works Replacement

- Hurricane Harvey resulted in record pool just 10 ft below crest.
- The recommended height from the VE Study would have overtopped.
- Significant damages would have occurred if the construction risk was on properly considered by the decision makers.

Cofferdam During Record Pool

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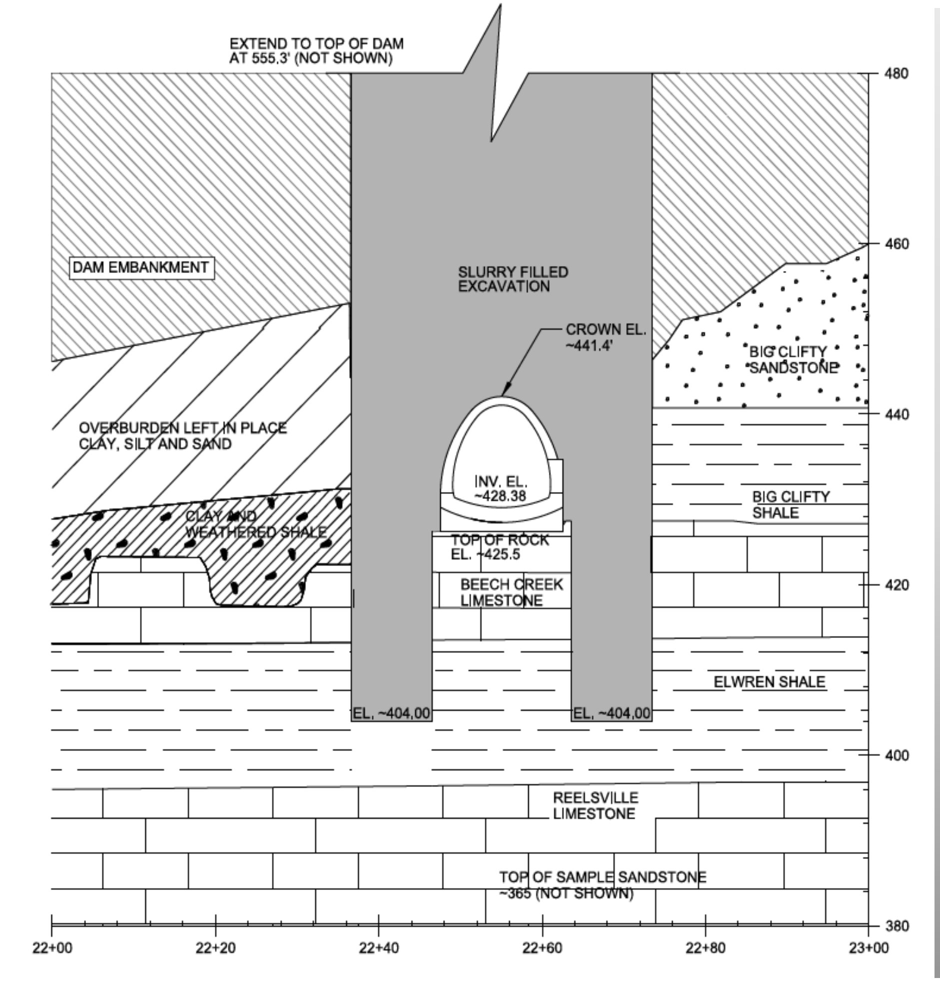
Case History- Cutoff Wall Interface With Outlet Works

- Cutoff wall to mitigate internal erosion into karst limestone foundation
- The most critical area adjacent and under existing outlet works conduit.
- A full cutoff through the conduit would provide the most risk reduction
- Operation of the outlet works is critical for flood control releases. No other means of discharge is available other than a open rock cut ungated spillway.

Case History- Cutoff Wall Interface With Outlet Works

An alternative plan was developed to build the cutoff wall around the conduit.

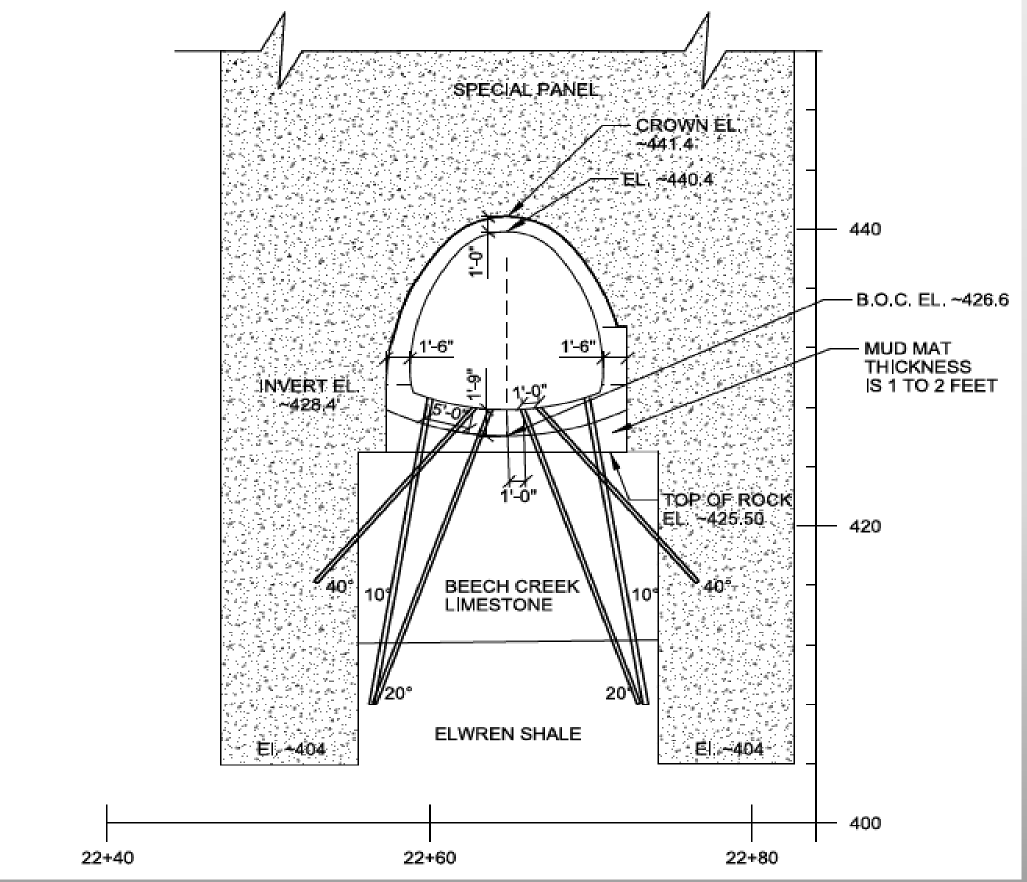
- Excavate panel above and around the conduit in a bentonite slurry
- Clean soil from the conduit surface
- Backfill panel with concrete.



Panel Excavation Plan Around Conduit

Case History- Cutoff Wall Interface With Outlet Works

After the concrete sets grouting would treat foundation under conduit.



Plan to Grout Through Conduit

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Case History- Cutoff Wall Interface With Outlet Works

- There was a concern for the slurry and concrete loading on the conduit structure.
- A structural steel liner was ruled out due to reduced outlet capacity
- A temporary steel bracing system was designed.
- Limits were placed on concrete lift heights for the cutoff wall panel
- Drawings and Specifications were developed

Case History- Cutoff Wall Interface With Outlet Works

- Final review indicated concerns with the structural integrity of the conduit
- A 3-D finite element analysis was performed to evaluate current and predicted construction loads.
- Results indicated that conduit was overstressed in its existing condition.
- Significant uncertainty in the construction and post construction loads on cutoff wall and conduit.

Case History- Cutoff Wall Interface With Outlet Works

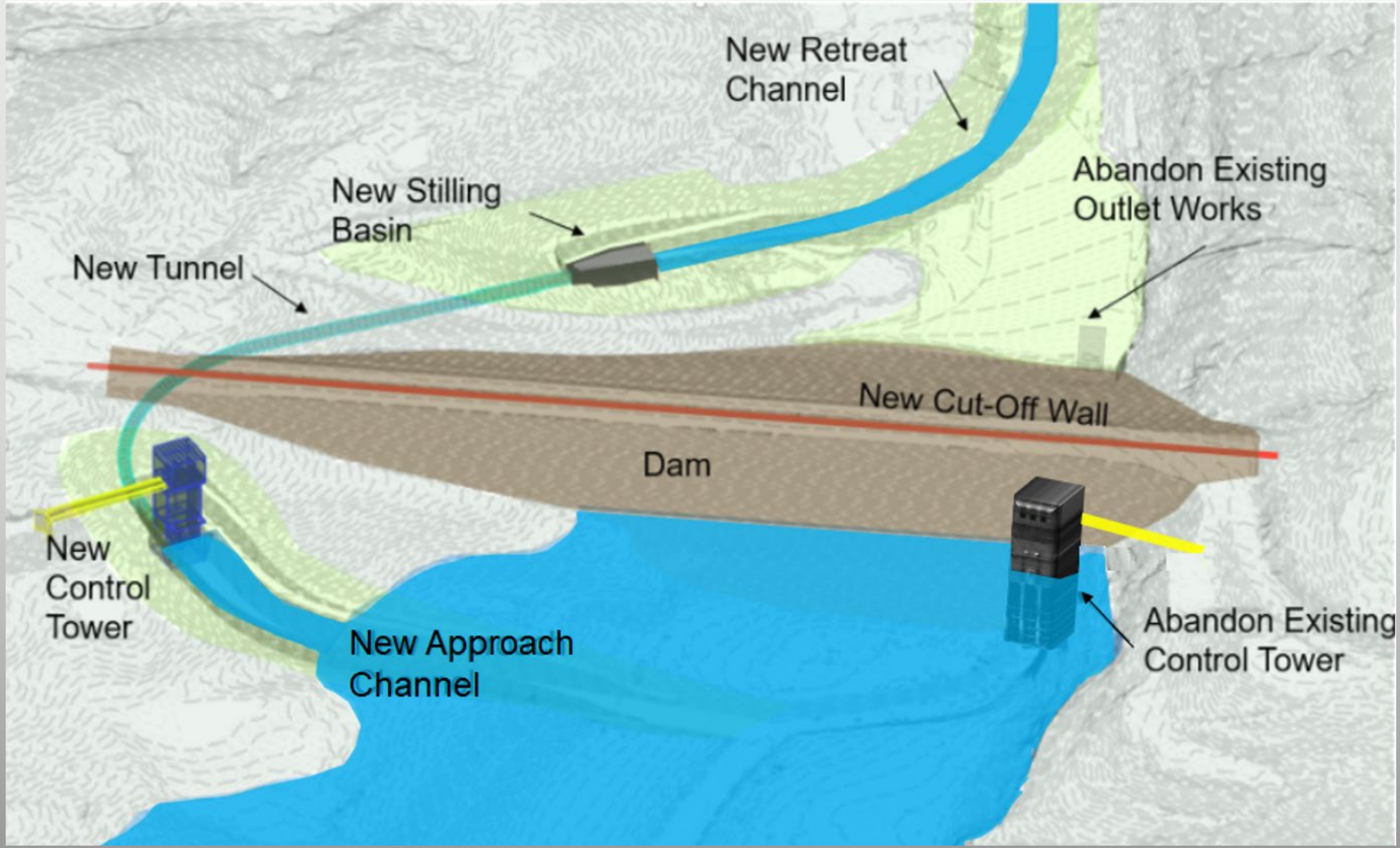
Decision makers determined that the construction risk of the alternative plan as designed was not acceptable.

- Revised structural analysis
- Uncertainty in construction and post construction loading
- Likelihood of structural damage to the conduit
- Increased potential for internal erosion into the conduit
- Potential for not being able to make water releases for a long period of time increasing overtopping risk.

Case History- Cutoff Wall Interface With Outlet Works

Final Selected Alternative

- New Intake Tower
- New Tunnel
- New Stilling Basin
- Abandon Existing Conduit
- Full Cutoff wall



Case History- Event Tree Analysis of Excavation at toe of an embankment dam

- Potentially liquefiable materials exist under the downstream shell of an embankment dam in a highly seismic area.
- Major town 1 mile downstream
- Reservoir fills in spring, lowers in summer, and has required drawdown in winter

Case History- Event Tree Analysis of Excavation at toe of an embankment dam

- Estimated risk justifies modification.
- Selected alternative for risk reduction is a trench to bedrock at the toe of the dam filled with cement-modified soil
- The trench requires a dewatering system to maintain stability

Case History- Event Tree Analysis of Excavation at toe of an embankment dam

Reservoir Water Surface Elevation (ft)	Probability of F.S.<1.0	
	Dewatering System Fails	Dewatering System Works
2470	4.0×10^{-2}	2.4×10^{-6}
2465	2.0×10^{-3}	2.4×10^{-6}
2445	4.0×10^{-4}	2.4×10^{-6}
2425	2.0×10^{-5}	2.4×10^{-6}

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Results of Probabilistic Slope Stability Analysis

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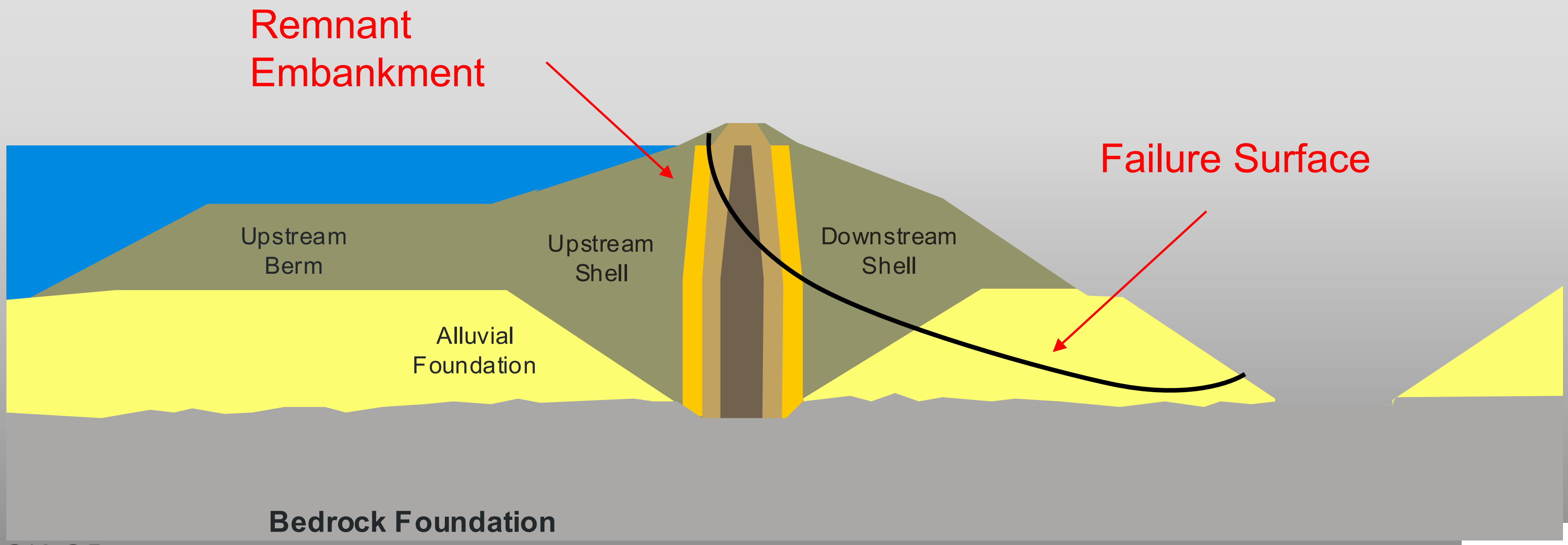
Case History- Event Tree Analysis of Excavation at toe of an embankment dam

Expert elicitation was used to estimate the probability that the remnant embankment would breach under the different pool levels.



Critical Surface from Slope Stability Analysis

Case History- Event Tree Analysis of Excavation at toe of an embankment dam

Reservoir Level (ft)	Exceedance Probability		
	March-June	July-October	November-February
2465+	0.012	0.0021	0.0002
2445	0.38	0.26	0.32
2425	0.80	0.62	0.39

Reservoir Exceedance Probability

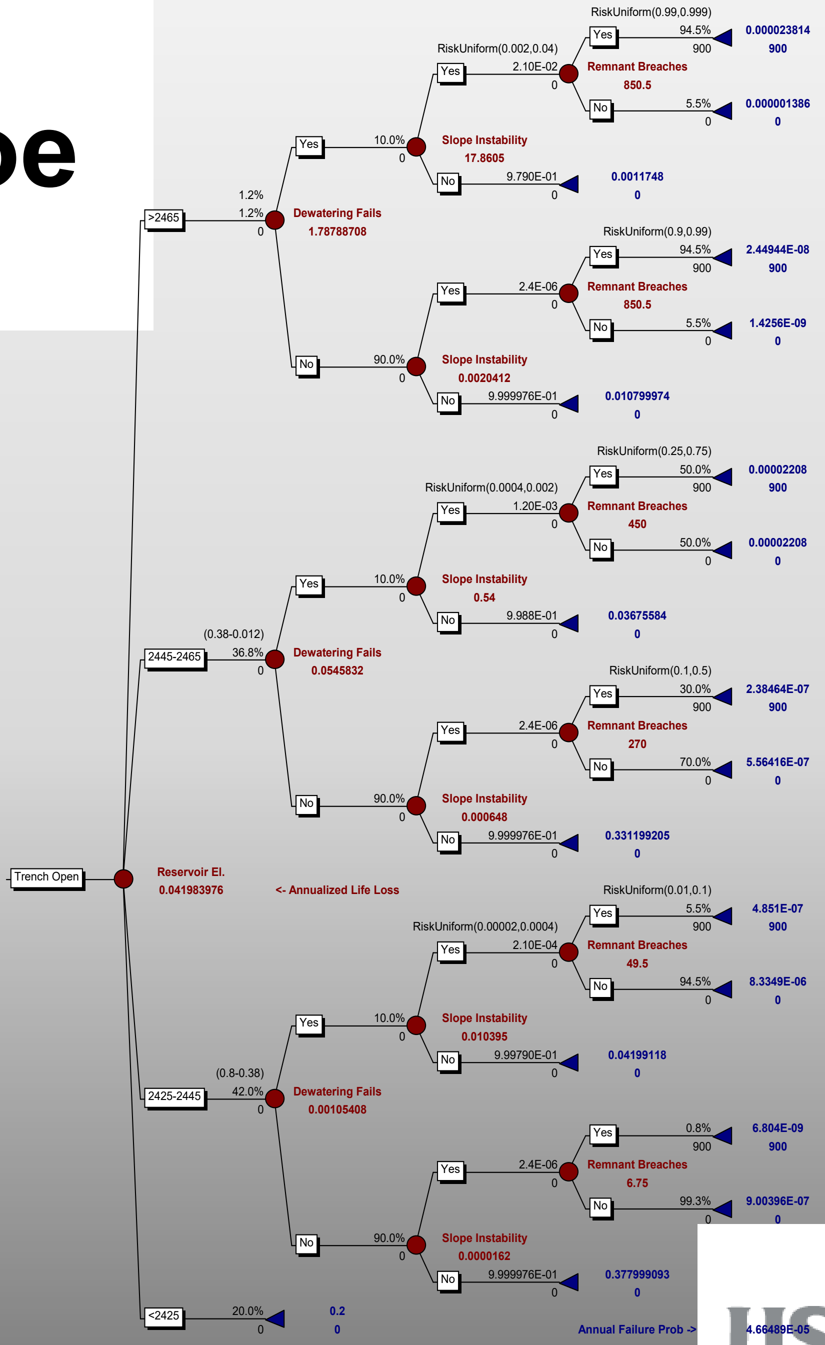
Case History- Event Tree Analysis of Excavation at toe of an embankment dam

- It was estimated that the dewatering system had a 10 percent chance of failing.

Dewatering System

Case History- Event Tree Analysis of Excavation at toe of an embankment dam

- Trench Open
- Reservoir is in a pool interval
- Dewatering fails
- Slope instability occurs
- Remnant embankment fails



March–June Event Tree

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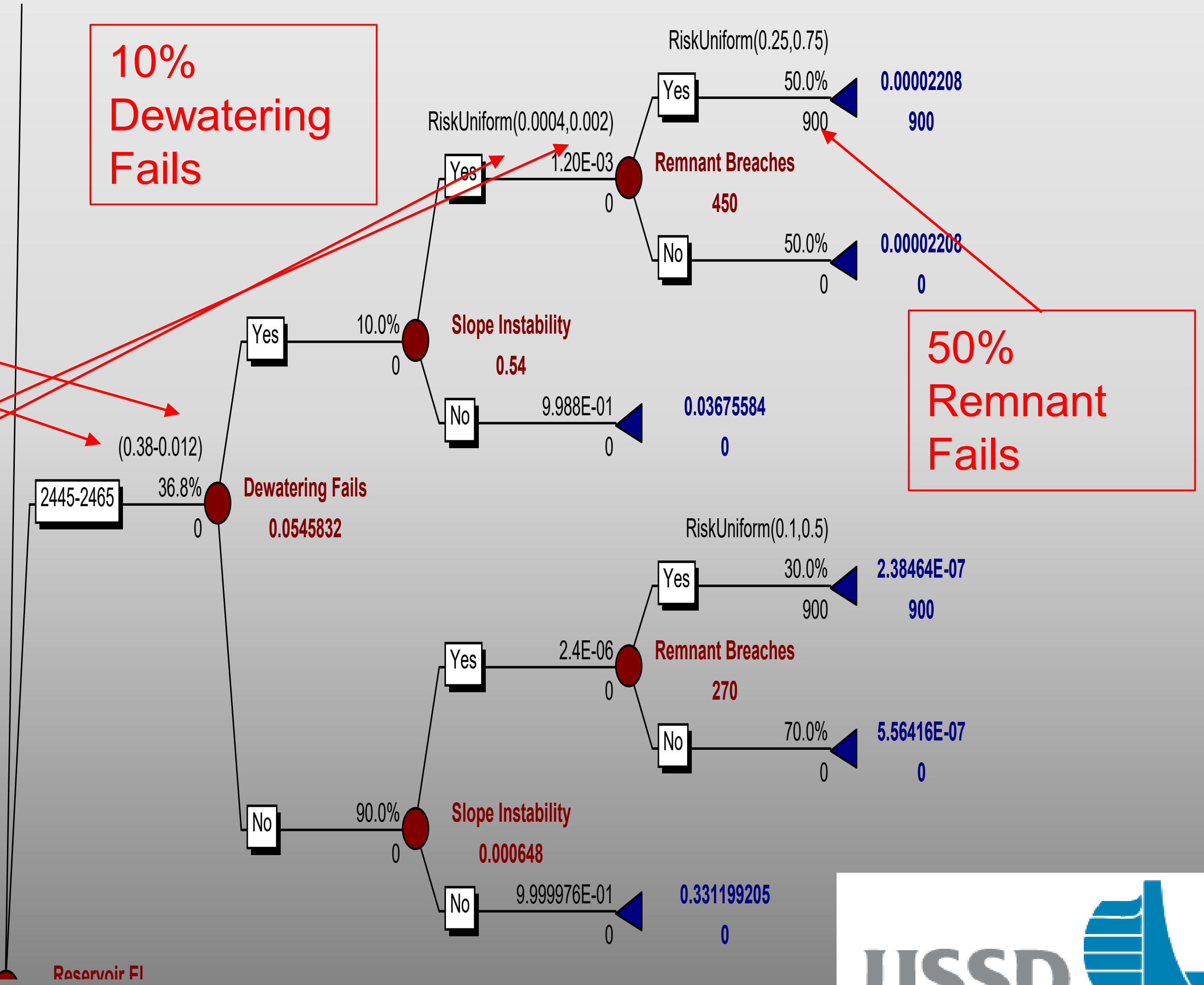
Case History- Event Tree Analysis of Excavation at toe of an embankment dam

Reservoir Level (ft)	Exceedance Probability		
	March-June	July-October	November-February
2465+	0.012	0.0021	0.0002
2445	0.38	0.26	0.32
2425	0.80	0.62	0.39

Pool Exceedance Probability

Reservoir Water Surface Elevation (ft)	Probability of F.S.<1.0	
	Dewatering System Fails	Dewatering System Works
2470	4.0×10^{-2}	2.4×10^{-6}
2465	2.0×10^{-3}	2.4×10^{-6}
2445	4.0×10^{-4}	2.4×10^{-6}
2425	2.0×10^{-5}	2.4×10^{-6}

Results of Probabilistic Slope Stability Analysis



Event Tree Branch for Pool Between 2445-2465

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Case History- Event Tree Analysis of Excavation at toe of an embankment dam

Season	Failure Probability	Loss of Life
March-June	4.66x10-5	4.20×10^{-2}
July-October	2.02x10-5	1.82×10^{-2}
November-February	1.99×10^{-5}	1.79×10^{-2}

Results for Each Period

Summary

- There are many conditions that can lead to increased risk during construction.
- Constructability Reviews should be performed to evaluate the risk
- Qualitative or Quantitative methods can be used
- Ways to mitigate the risk should be explored
- Construction timing and schedule adjustments should be evaluated for each alternative.
- A risk informed decision on construction risk can be made if all the key information is considered and made available to the decision makers in a timely fashion.
- Do no harm.

Questions???

Thank You!

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