Mekong River Commission
For Sustainable Development

MRC Regional Training Workshop on Dam Safety (2025), Vang Vieng, Lao PDR.

Design Guidance for Proposed Mainstream Dams in the Lower Mekong Basin (PDG2O22)

Dam Safety Review, Seismic Hazard Analysis and Risk Assessment

EGAT

Presented by

Montri Jinakulwipat

Head, Dam Safety Analysis Section,

Dam Safety Department, Civil Maintenance Division

Pothikul Vivithkeyoonvong

Engineer Level 6, Dam Safety Analysis Section,

Content

1. Introduction of Dam Safety Program
2. Importance of Dam Safety Review
3. Procedure of Dam Safety Review
4. Seismic Safety Review
    - Hazard Classification,
    - Seismic Hazard Analysis
    - Dynamic Response Analysis
5. Risk Assessment Analysis

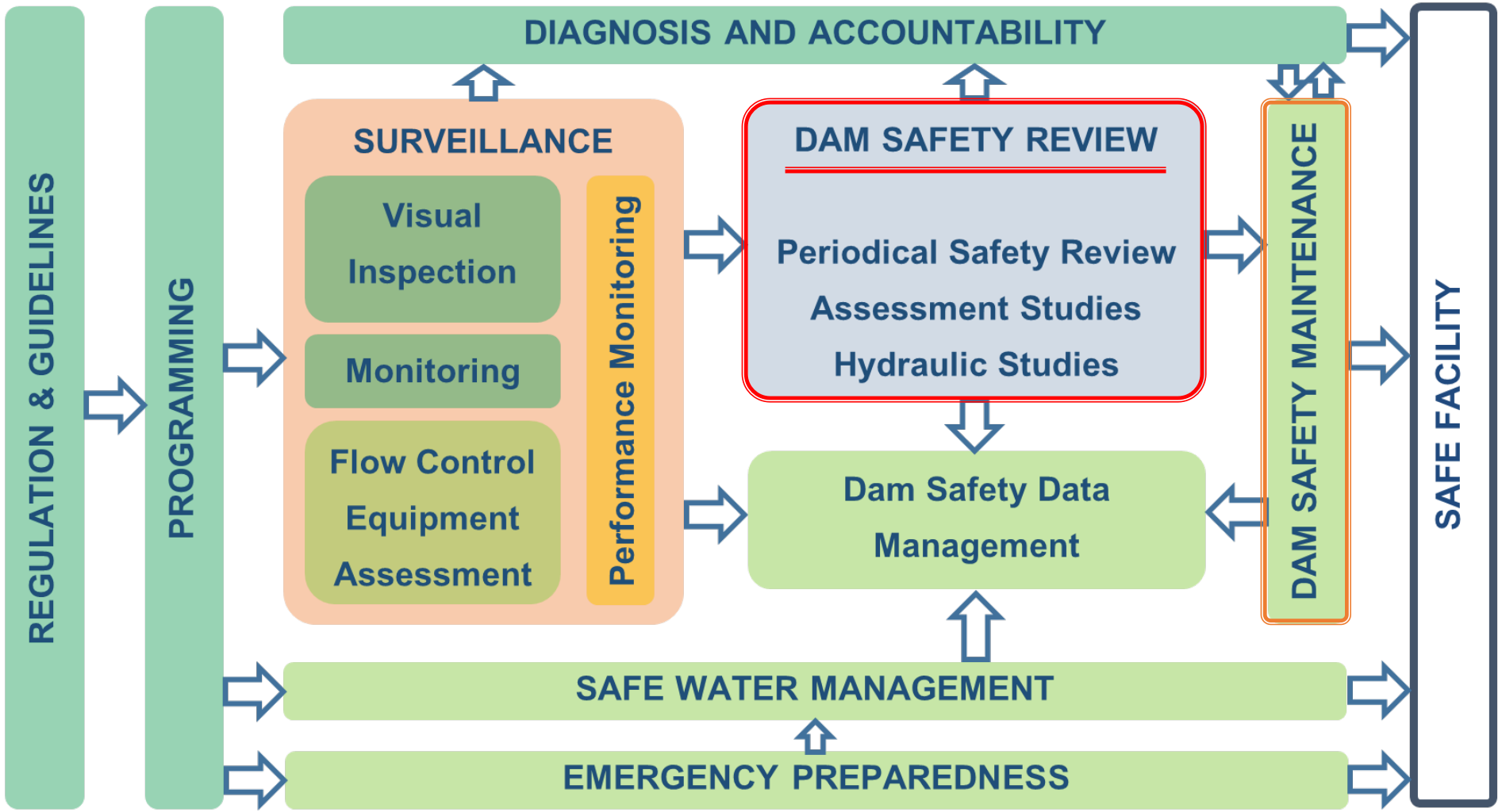


Introduction

- **Risk Assessment Analysis**
- **Dam Safety Review**
- **Seismic Hazard Analysis (Seismic Review)**

Dam Safety Program

Source: ICOLD Bulletin 138 General approach to Dam Surveillance



Dam Safety Review



Is dam failure happening anymore?

Teton Dam, USA (1976)
Failure from internal erosion



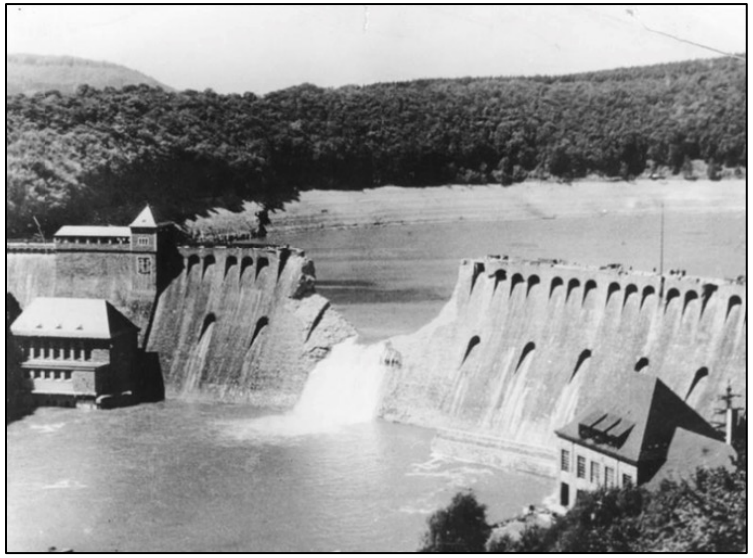
Loss of life = 11
Livestock loss ≈13,000

Vajont Dam, Italy (1963)
Overtopping due to landslide in the reservoir



Loss of life ≈ 2,000

Banqiao and Shimantan Dams, China (1975)
Precipitation exceeded design storage capacity



Loss of life between 26,000 and 240,000
11 million people displaced

Dam failures are still happening!

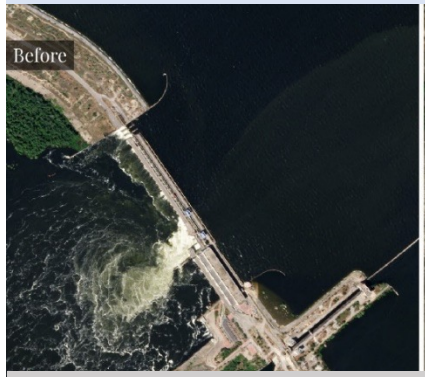
Al-Bilad Dam, Libya (2023)
Overtopping due to
flood and lack of maintenance

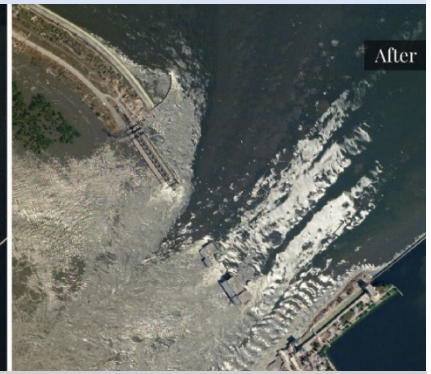


Loss of life ≈ 20,000



Kakhovka Dam, Ukraine (2023)
Bombing





Loss of life = 58



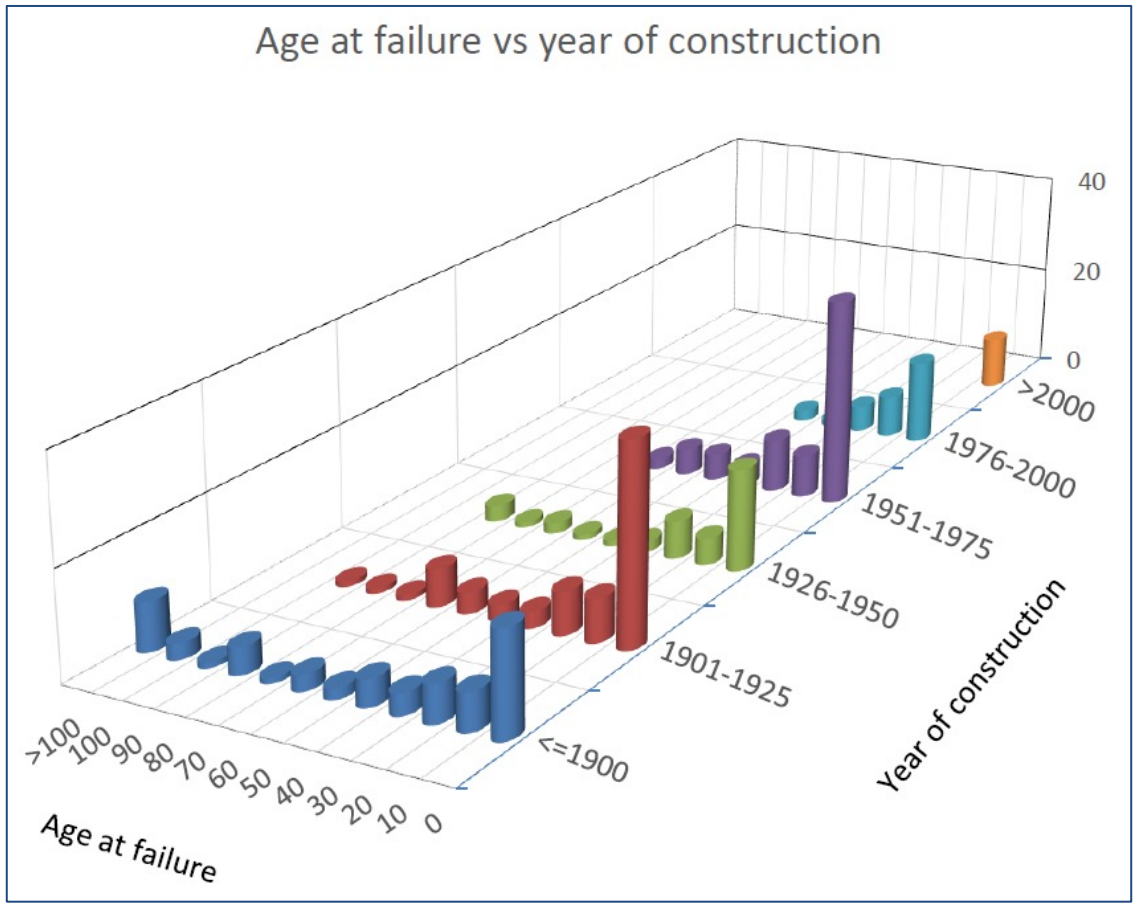
Xe-Pian Xe-Namnoy Saddle Dam D,
Laos PDR (2018) Failure due to inadequate
foundation treatment



Loss of life = 36



Importance of Dam Safety Review and Risk Analysis



Source: ICOLD Bulletin 188 (Preprint) Dam failures - Statistical analysis

Even though most of dam failures occur within the first 10 years after dam's completion, **older dams also have risk of failure** from many causes such as

- **Deterioration** of dam materials and water releasing structures
- **Outdated** design and construction **standards**
- **Changes in conditions** of dam and reservoir use
- **Lack of maintenance**
- **Climate change**
- War and terrorism

Dam Safety Review Procedure

- ✓ Dam data collection and review
- ✓ Dam inspection
- ✓ Dam and foundation material testings
- ✓ Dam behavior analysis from monitoring instruments
- ✓ Dam stability analysis
- ✓ Potential failure mode analysis
- ✓ Dam failure consequence analysis
- ✓ Dam safety risk assessment
- ✓ Dam safety activity evaluation
- ✓ Conclusions and recommendations



Necessary Data for Analysis

Data for Dam Safety Analysis

❖ Literature Review

e.g Completion Report, As-built Drawing, Specifications, Maintenance history

❖ Dam Material Testing

e.g. Borehole Drilling , Resistivity Survey, Multichannel Analysis of Surface Waves (MASW)

❖ Dam Inspection

e.g. Visual Inspection (dam crest, dam slopes, abutments, dam toe, appurtenant structures)

❖ Data from Instruments

e.g. Settlement and Displacement of Dam Crest and Dam Slope, Pore Water Pressure, Seepage Rate

Data from Dam Material Testing

Drilling and Testing

To determine types and properties of dam and foundation materials which might be different from the design/completion documents

Electrical Resistivity Survey

To determine moisture in embankment and foundation materials which may indicate seepage/leakage area

Multichannel Analysis of Surface Waves

To determine shear wave velocity of dam and foundation materials for dynamic analysis

Data from Dam Material Testing

Drilling and Testing

- Soil type according to Unified Soil Classification System (USCS)
- Permeability
- Specific gravity, Unit weight
- Natural water content, Liquid limit, Plastic Index
- Strength parameters (Friction Angle, Cohesion)
- Rock hardness and weathering, Uniaxial Compressive Strength (UCS)
- Coefficient of Consolidation
- Dispersiveness, Swelling

Drilling on dam crest



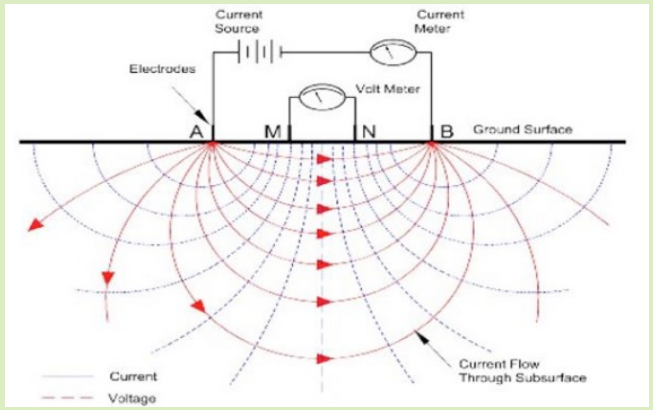


Triaxial Test

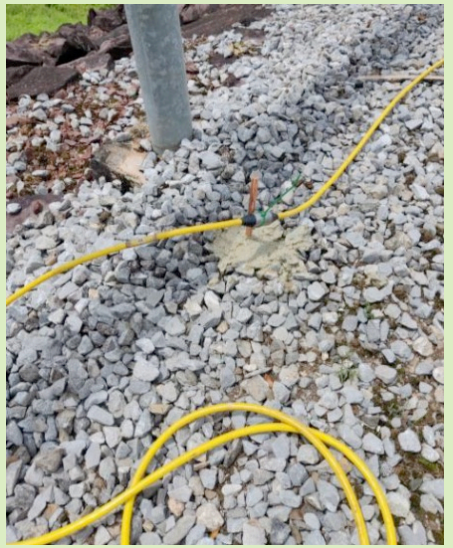
Data from Dam Material Testing

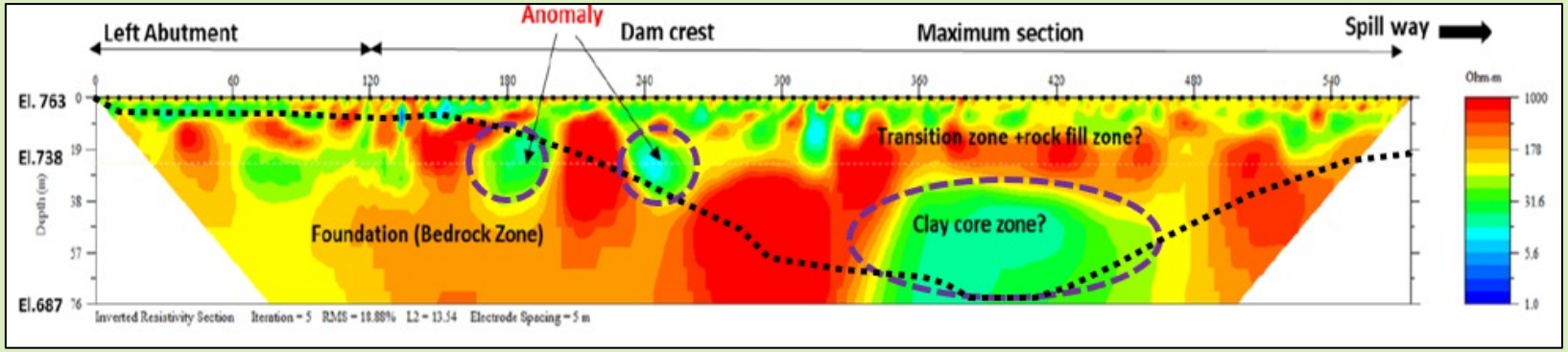
Resistivity Survey

Measures the electric potential differences in embankment and foundation. Resulting values depend on material properties of each area such as minerals, moisture, density, porosity, degree of saturation, and chemical composition.





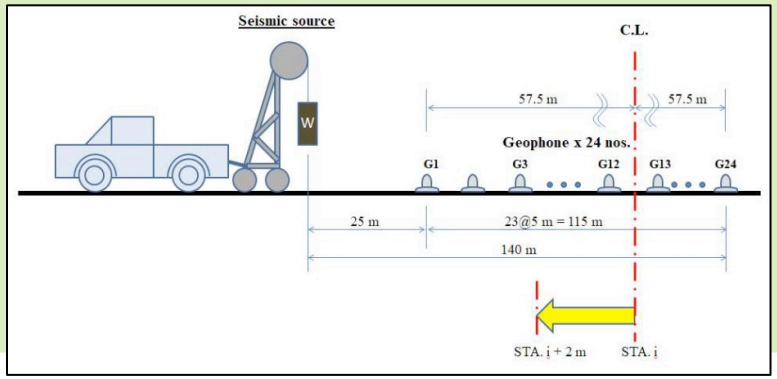




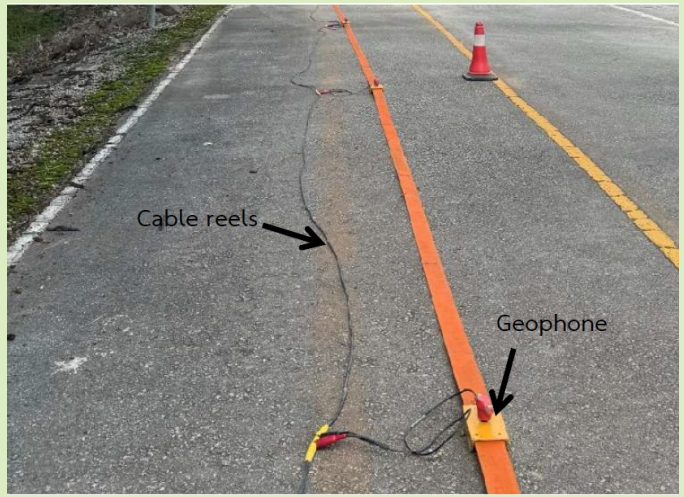
Data from Dam Material Testing

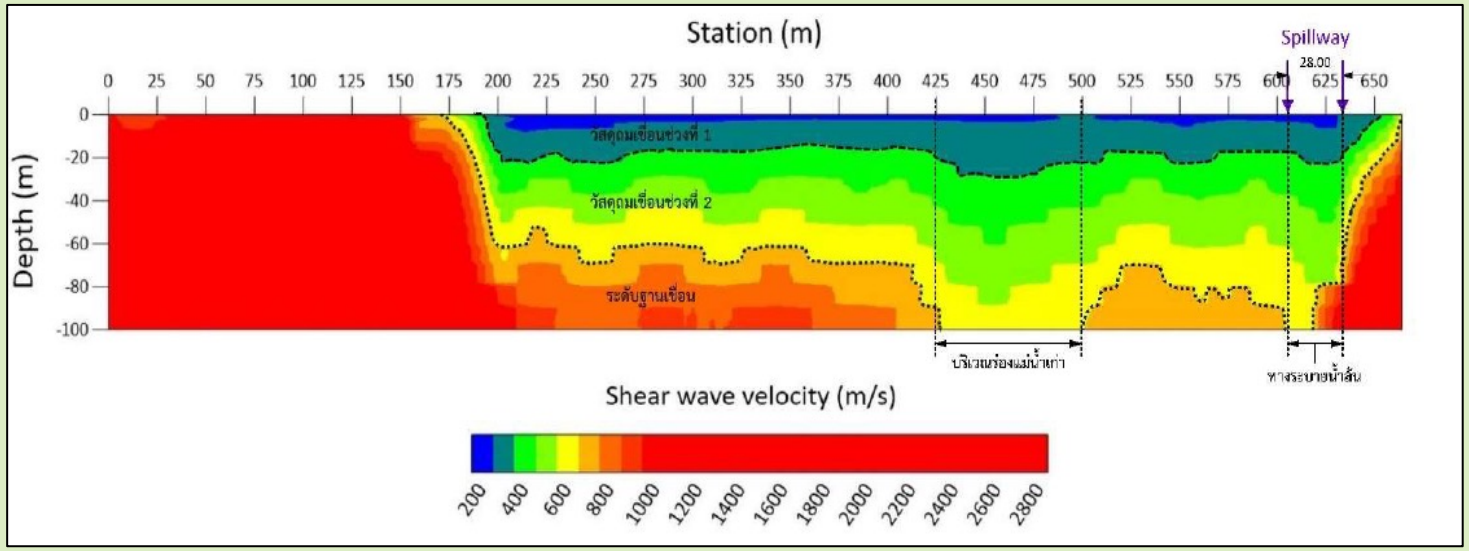
Multichannel Analysis of Surface Waves

A subsurface investigation to assess geological characteristics and stratigraphy by generating seismic waves and measuring the travel time of the waves from the source point to the receiver (Geophone). The wave velocity is directly correlated with the density and type of soil/rock, and this data is used to calculate the Shear Wave Velocity.



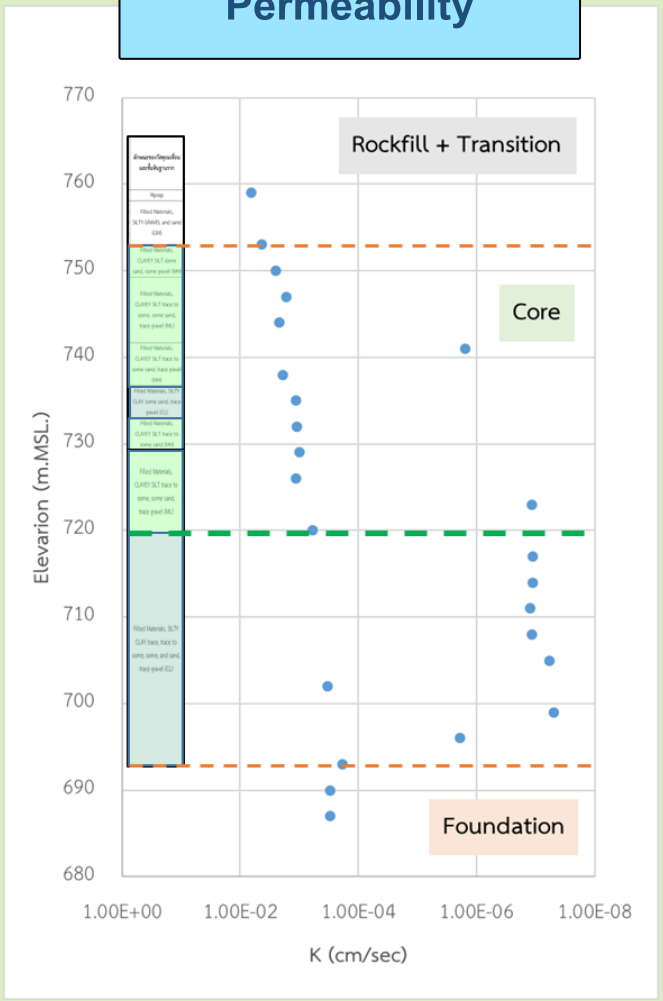




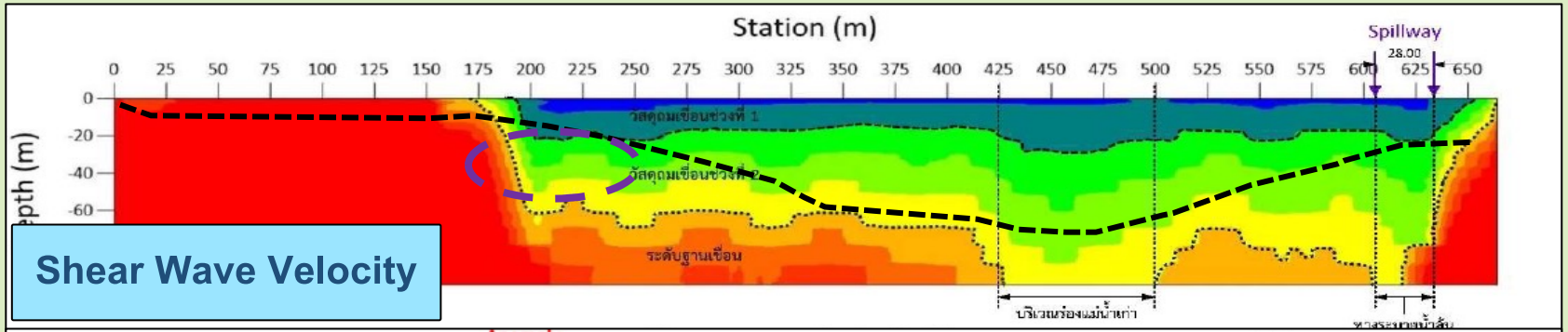


Combine Data from Dam Material Testing

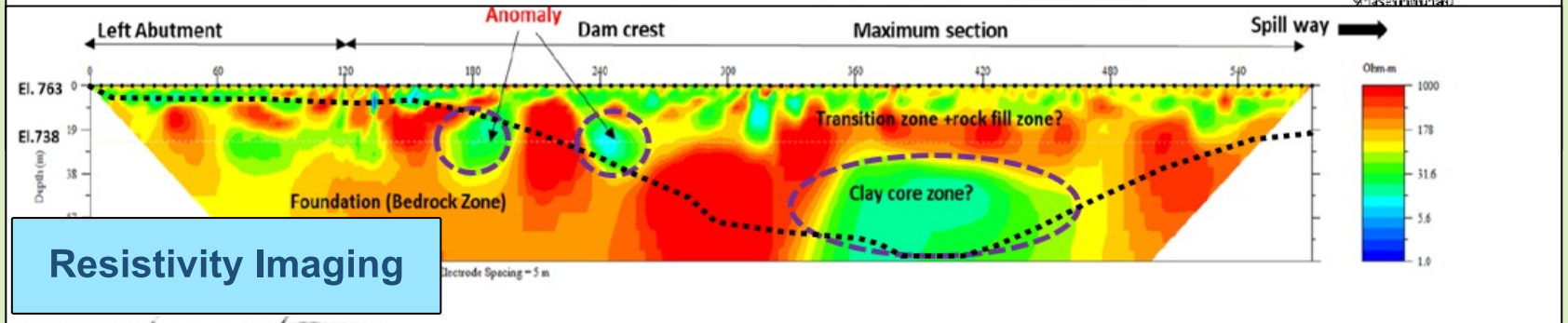
Permeability



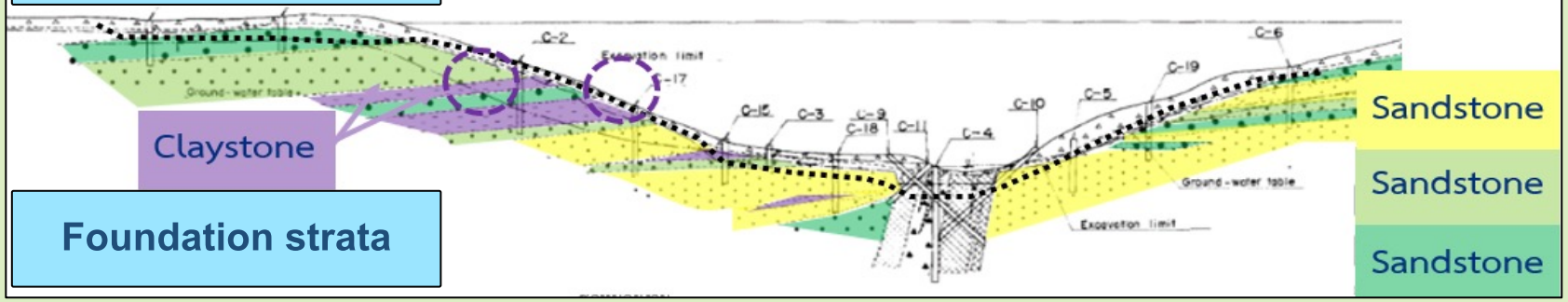
Shear Wave Velocity



Resistivity Imaging



Foundation strata

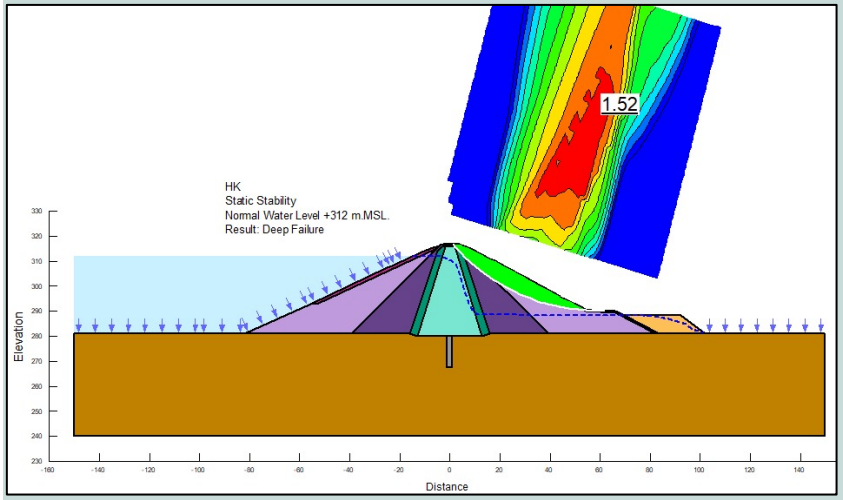


Dam Modeling -- to evaluate dam stability and seepage behavior

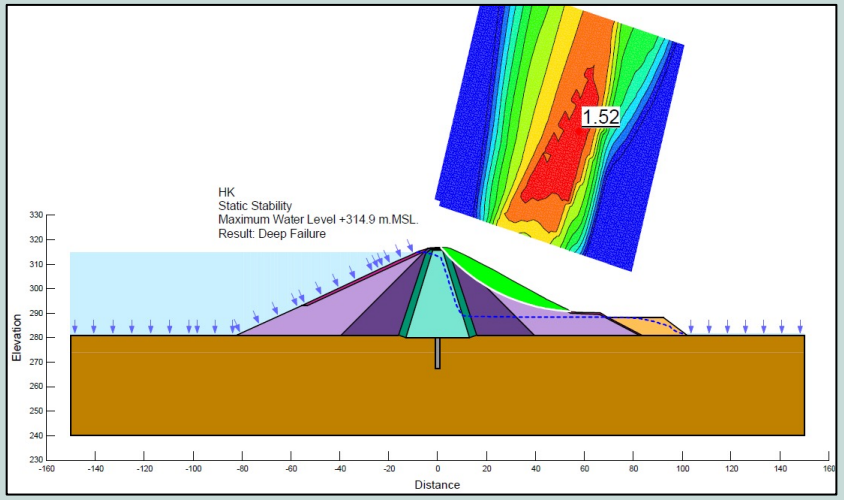
Factor of Safety (F.S.)

USBR: DS13-4 Design Standards Embankment Dam STATIC STABILITY ANALYSIS, 2011

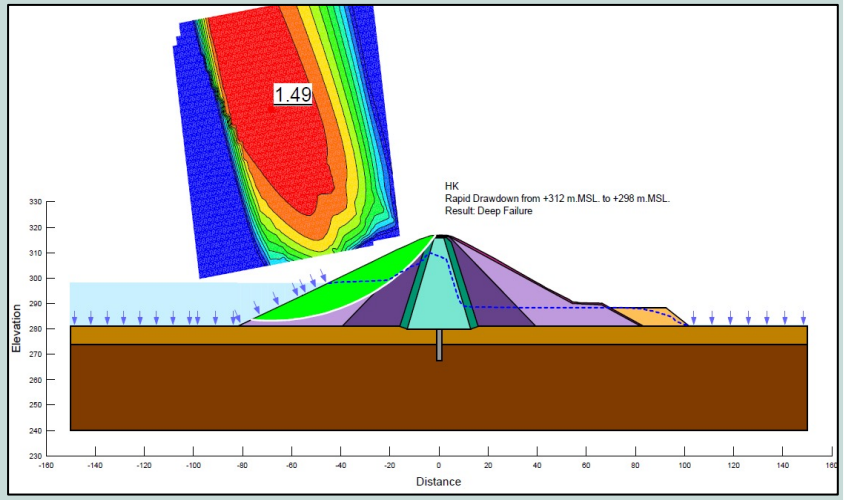
Loading	Slope	Min FS
N.H.W.L	Downstream	1.5



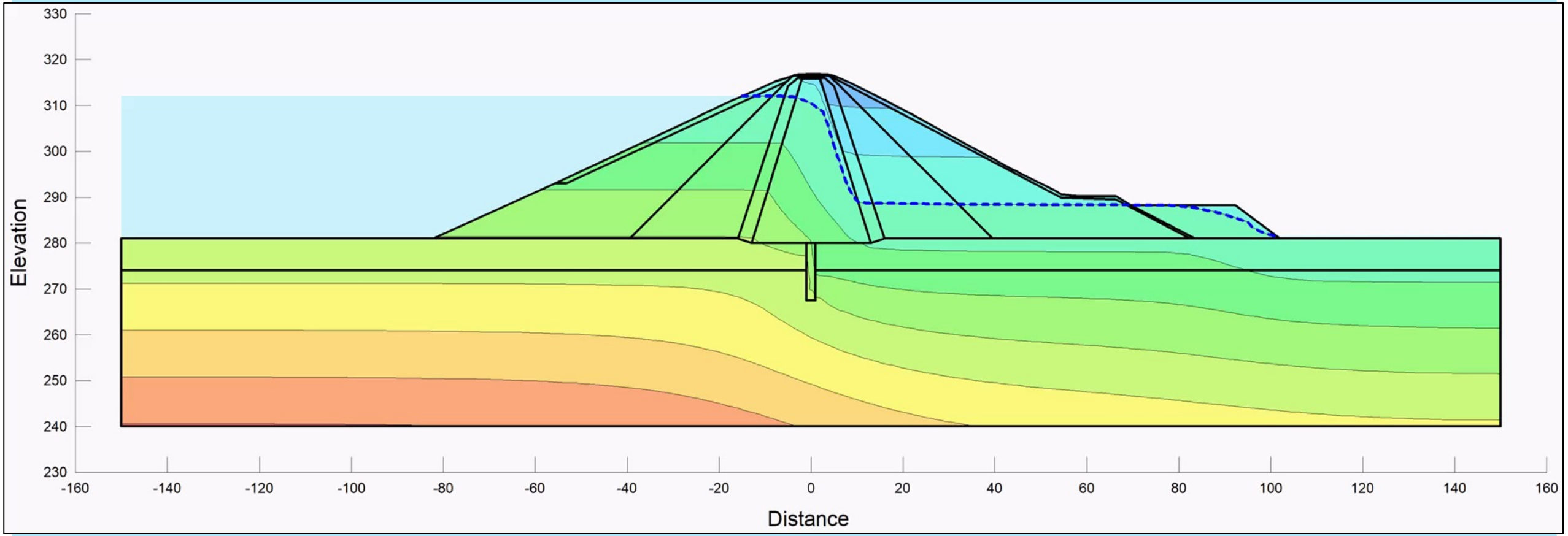
Loading	Slope	Min FS
M.H.W.L	Downstream	1.2



Loading	Slope	Min FS
Rapid Drawdown	Upstream	1.2 - 1.3



Dam Modeling -- to evaluate dam stability and seepage behavior

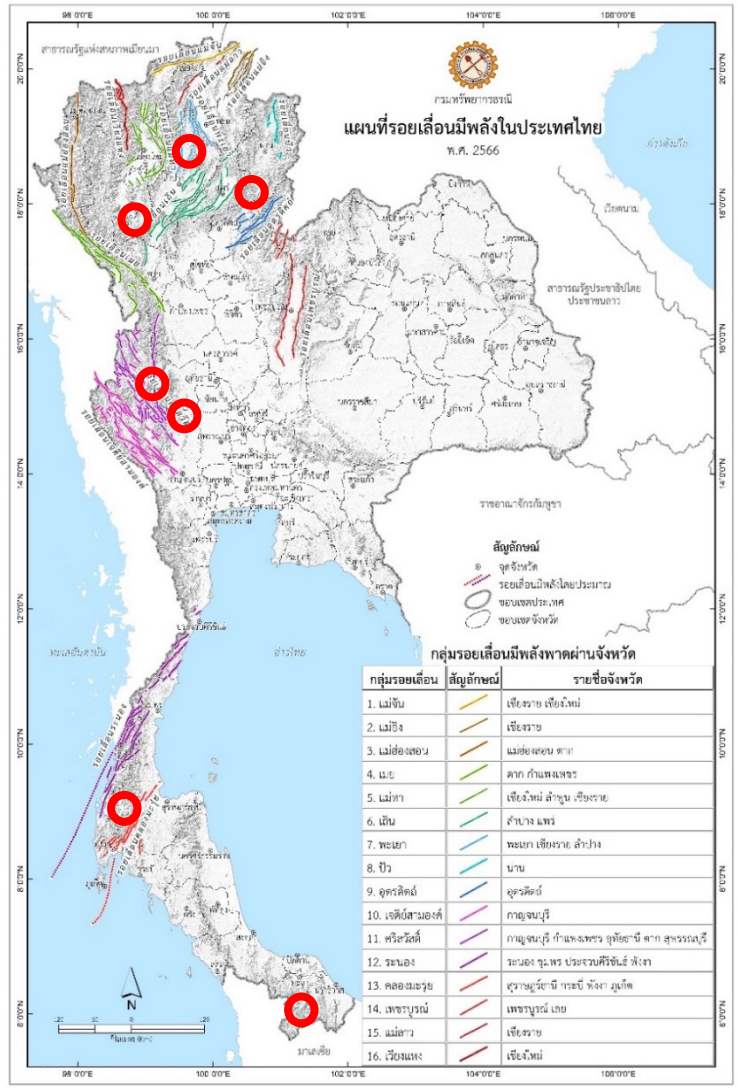


Seismic Dam Safety Reviews

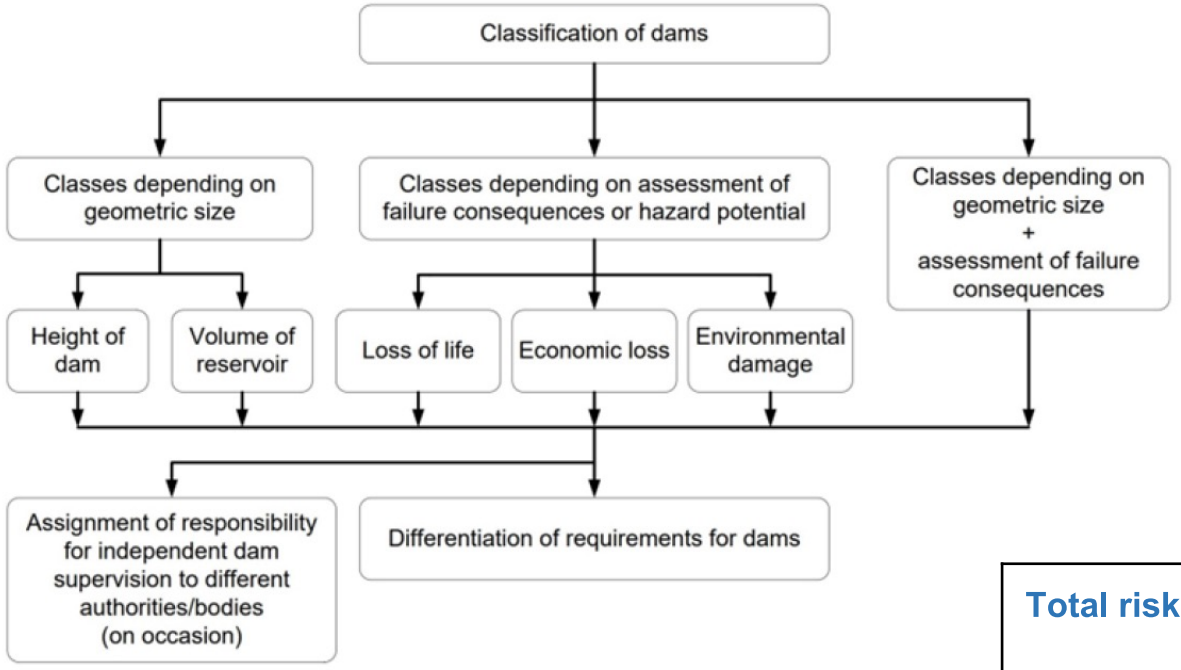


Large 14 EGAT' Dam 7 Dams on high potential seismicity





Hazard Classification



ICOLD Bulletin167 (2017)

Risk Factor	Extreme	High	Moderate	Low
	Contribution to risk (weighting points)			
Capacity (hm^3)	120 (6)	120-1 (4)	1-0.1 (2)	<0.1 (0)
Height (m)	45 (6)	45-30 (4)	30-15 (2)	<15 (0)
Evacuation requirements (No. of persons)	>1000 (12)	1000-100 (8)	100-1 (4)	None (0)
Potential downstream damage	High (12)	Moderate (8)	Low (4)	None (0)

Total risk factor	Risk class (Risk ratings)	Seismic input parameter for analysis
0 - 6	I (Low)	SEE 1000 year
7 - 18	II (Moderate)	SEE 3000 year
19 - 30	III (High)	SEE 10000 year (MCE)
31 - 36	IV (Extreme)	SEE 10000 year (MCE)

Seismic Design (Evaluation)

ขนาดแผ่นดินไหว (Earthquake Magnitude)	ระดับความเสี่ยงภัยของเขื่อน (Risk Class)		
	ระดับสูงหรือสูงสุด (Extreme or High)	ระดับกลาง (Moderate)	ระดับต่ำ (Low)
MCE (Maximum Credible Earthquake)	ต้องพิจารณาที่ระดับนี้	สามารถลดทอนขนาดลงจาก MCE ได้	สามารถลดทอนขนาดลงจาก MCE ได้
SEE* (Safety Evaluation Earthquake)	Deterministic เลือกเปอร์เซ็นไทล์ที่ 84 (84^{th} percentile) ซึ่งเทียบเท่า Mean + 1SD	Deterministic เลือกเปอร์เซ็นไทล์ที่ 50 ถึง 84 (50^{th} to 84^{th} percentile)	Deterministic เลือกเปอร์เซ็นไทล์ที่ 50 (50^{th} percentile)
	Probabilistic เลือกที่ mean AEP ไม่น้อยกว่า 1/10,000	Probabilistic เลือกที่ mean AEP ไม่น้อยกว่า 1/3,000	Probabilistic เลือกที่ mean AEP ไม่น้อยกว่า 1/1,000
OBE* (Operation Basis Earthquake)	คำนวณจากข้อกำหนดการออกแบบ (Seismic Building Code) พิจารณาที่คาบอุบัติซ้ำ (Return Period) 475 ปี		

mean AEP: mean annual exceedance probability

Deterministic (Worst Case Scenario) Approach vs Probabilistic Approach

Dam safety analysis by **deterministic approach** using the **worst case scenario**, such as Probable Maximum Flood event or Maximum Credible Earthquake event, has **extremely low probability**. **Is it necessary**?

Yes! If the dam is determined to be high consequence dam (a dam whose failure would likely cause severe harm to life, property, and the environment)

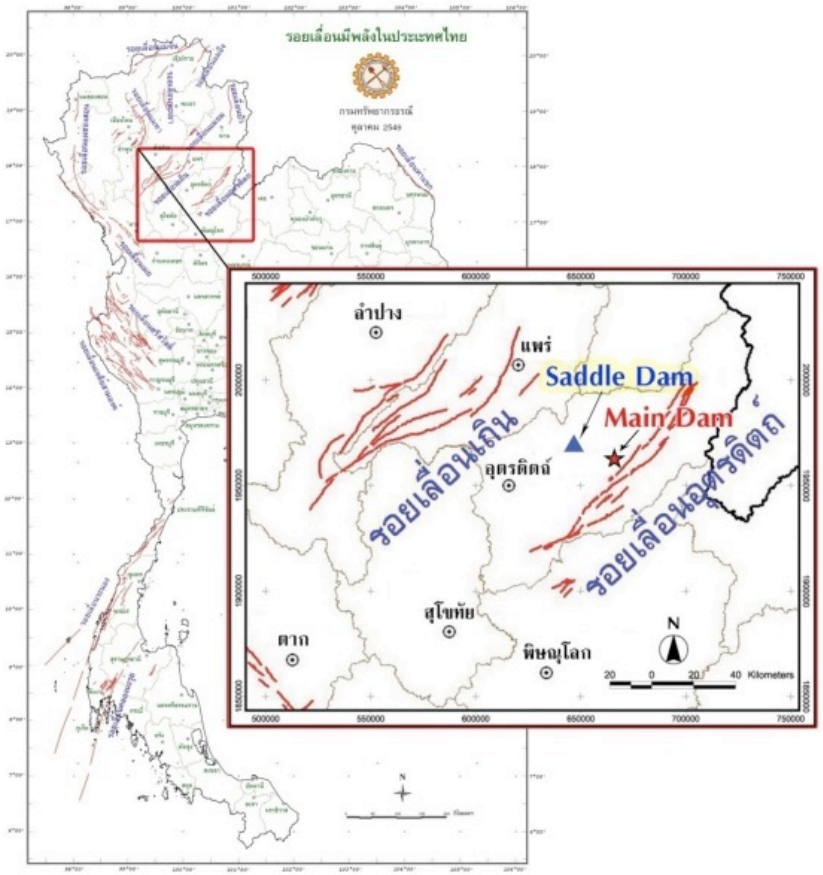
If the worst case scenario is already evaluated, is **probabilistic analysis still necessary**?

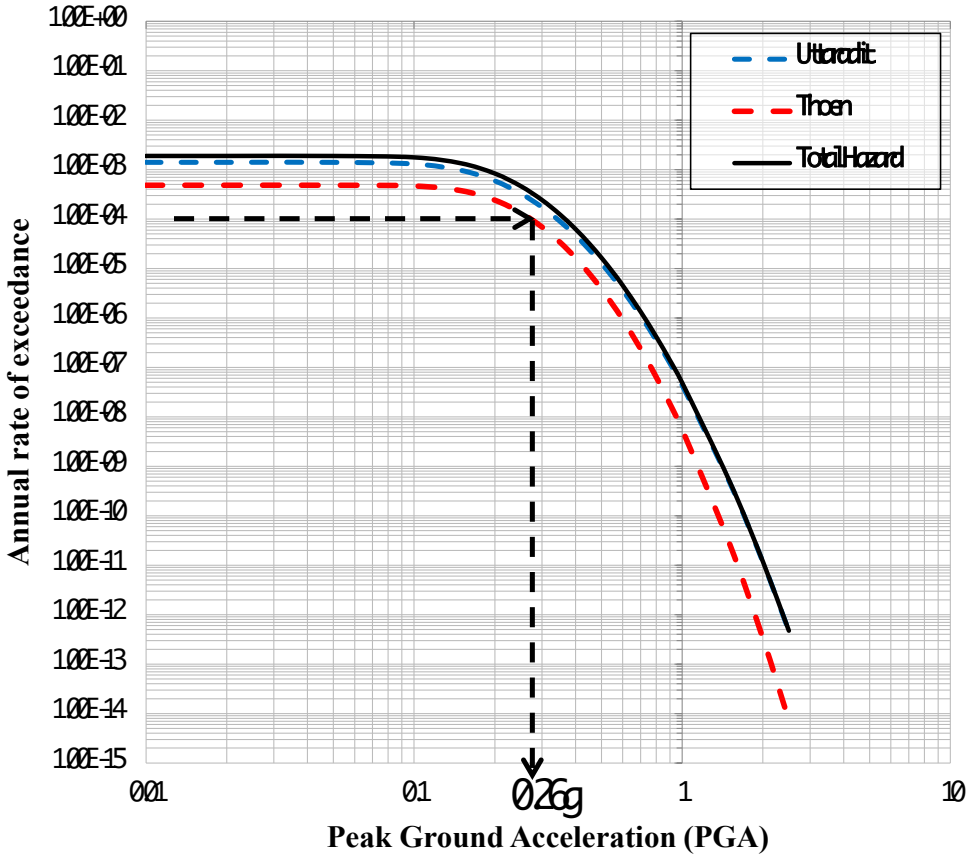
Yes! Because probabilistic analysis …

- takes into consideration **uncertainty** which is a result of incomplete data, variability in nature, changes in environment, knowledge gap, etc.
- **identifies scenarios** that may not be the worst but have **higher probability**
- informs **risk management within limited budget and resources**

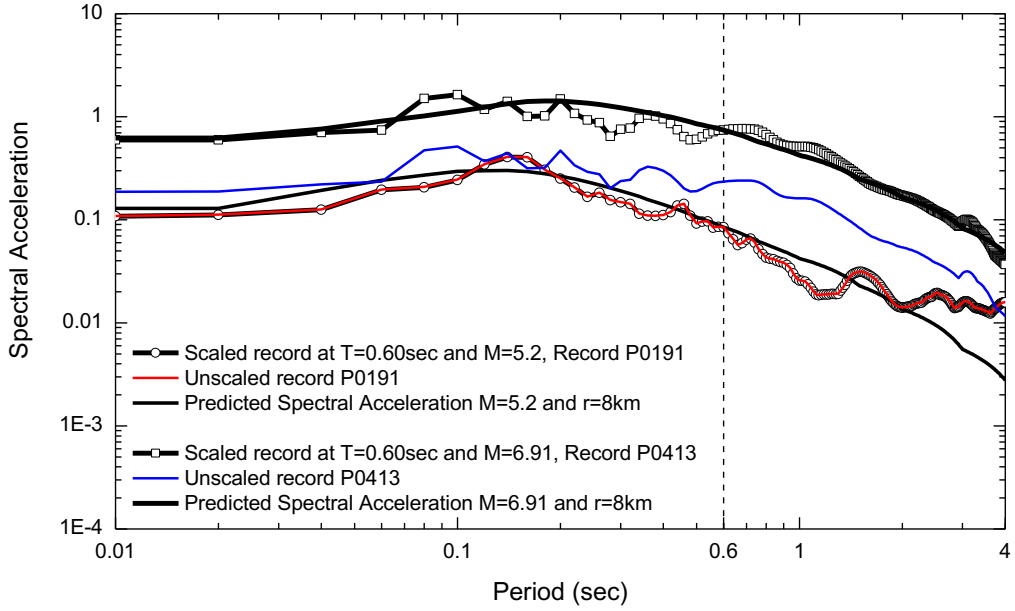
Seismic Hazard Analysis

1. Deterministic Seismic Hazard Analysis (DSHA)
2. Probabilistic Seismic Hazard Analysis (PSHA)



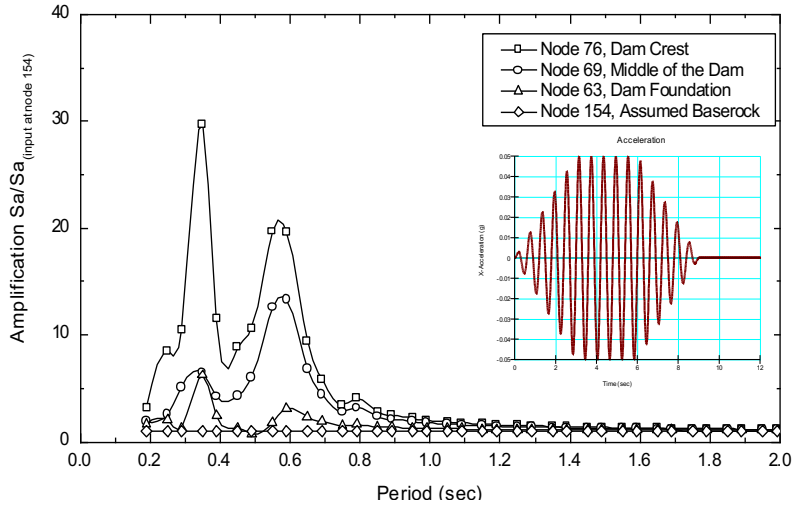


Ground Motion Selection

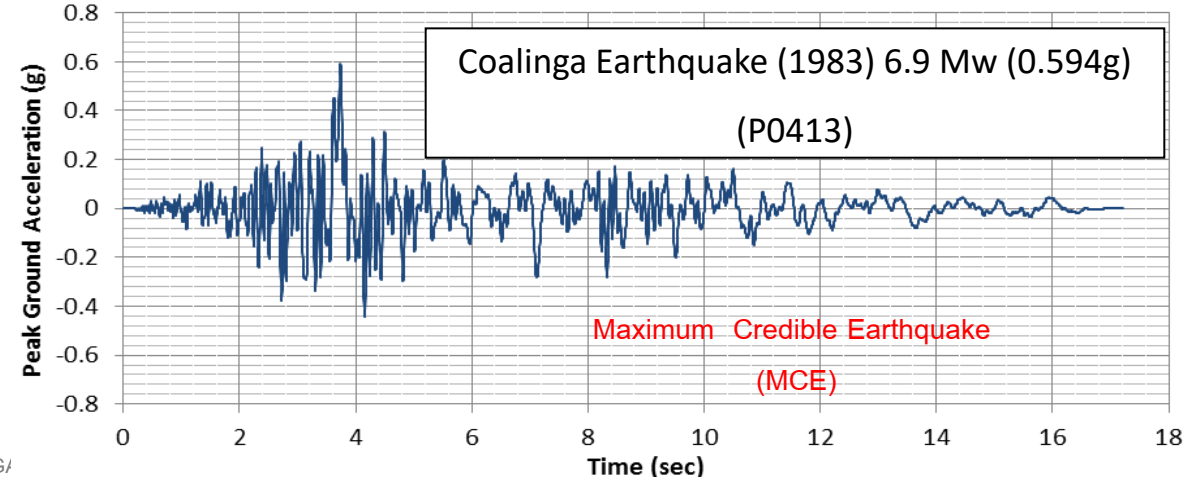


OBE - Operating Basis Earthquake
50% in 100 years, 145 years return period
M=2.9735-*log*(1/145) =5.134=5.2

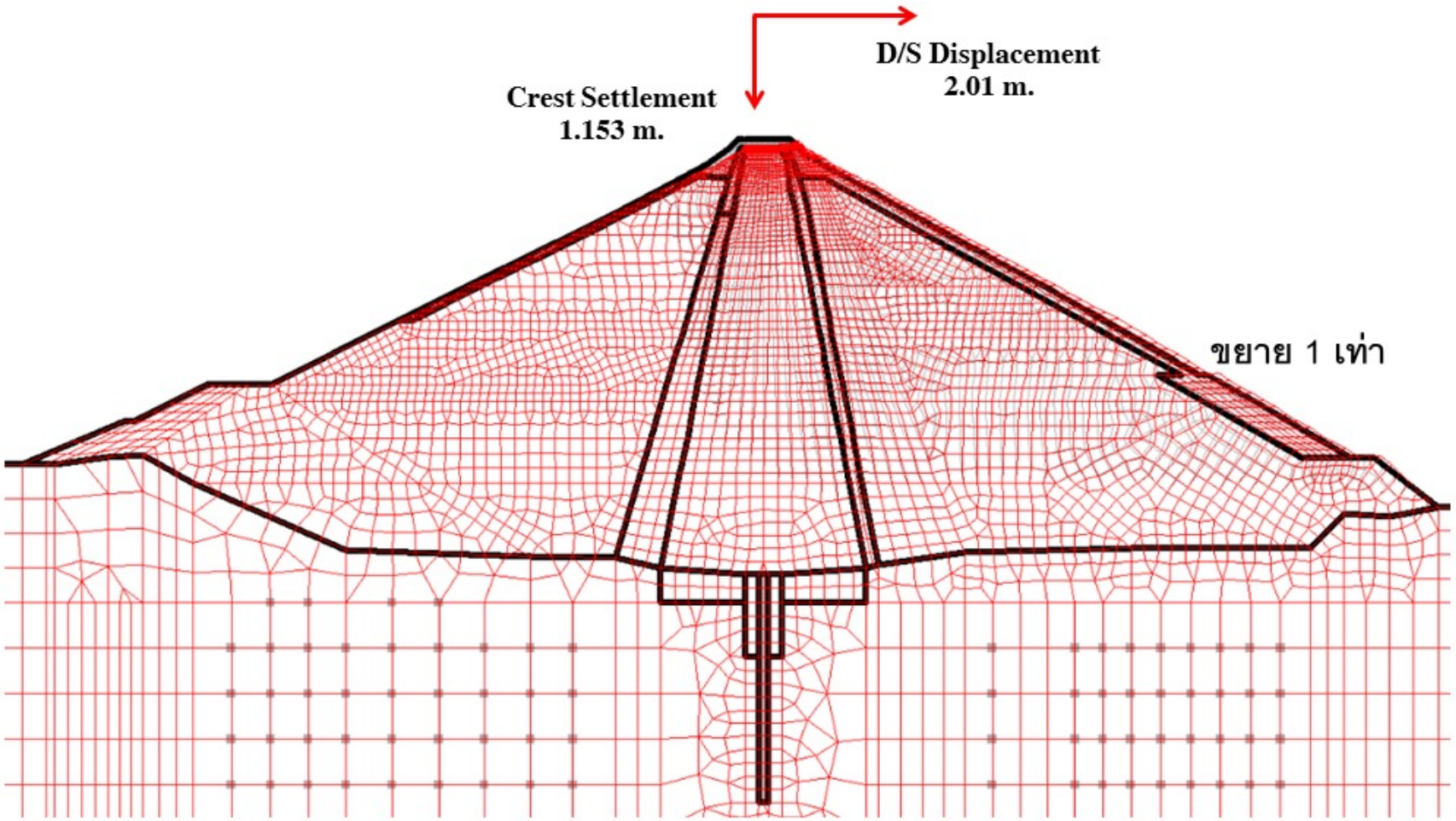
MCE – Maximum Credible Earthquake
10% in 50 years, 475 years return period
M=2.9735-*log*(1/475) =5.650=5.7



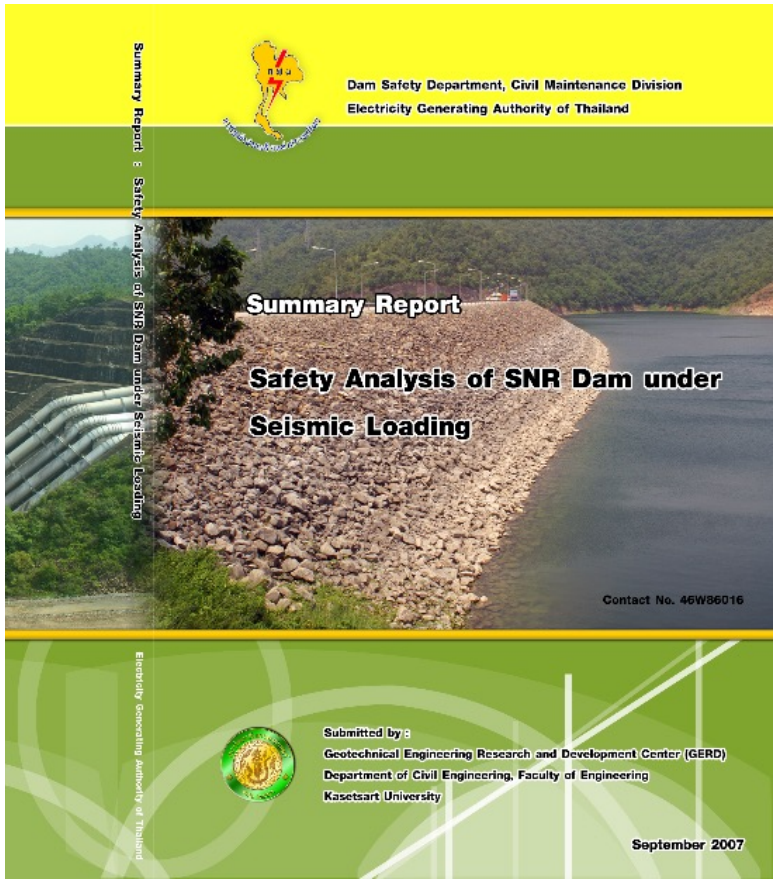
Earthquake Type	Magnitude (Mw)	PGA (g)
OBE (Average Mean Spectrum Acceleration, 50%)	5.2	0.109
MCE (Average Mean Spectrum Acceleration, 50%)	6.91	0.594
OBE (Condition Mean Spectrum Acceleration, 98%) :	5.2	0.243
MCE (Condition Mean Spectrum Acceleration, 98%)	6.91	1.292



Seismic Deformation Modeling Results



Seismic Safety Reviews of EGAT Dam







Risk Analysis for Dams



Objective of Risk Analysis

- To identify potential hazards that may affect dam safety.
- To evaluate the likelihood (probability) and consequences of failure scenarios.
- To support decision-making for dam operation and maintenance.
- To enhance public safety and protect downstream communities.
- Comply with international standards (e.g., ICOLD, USBR, USACE).

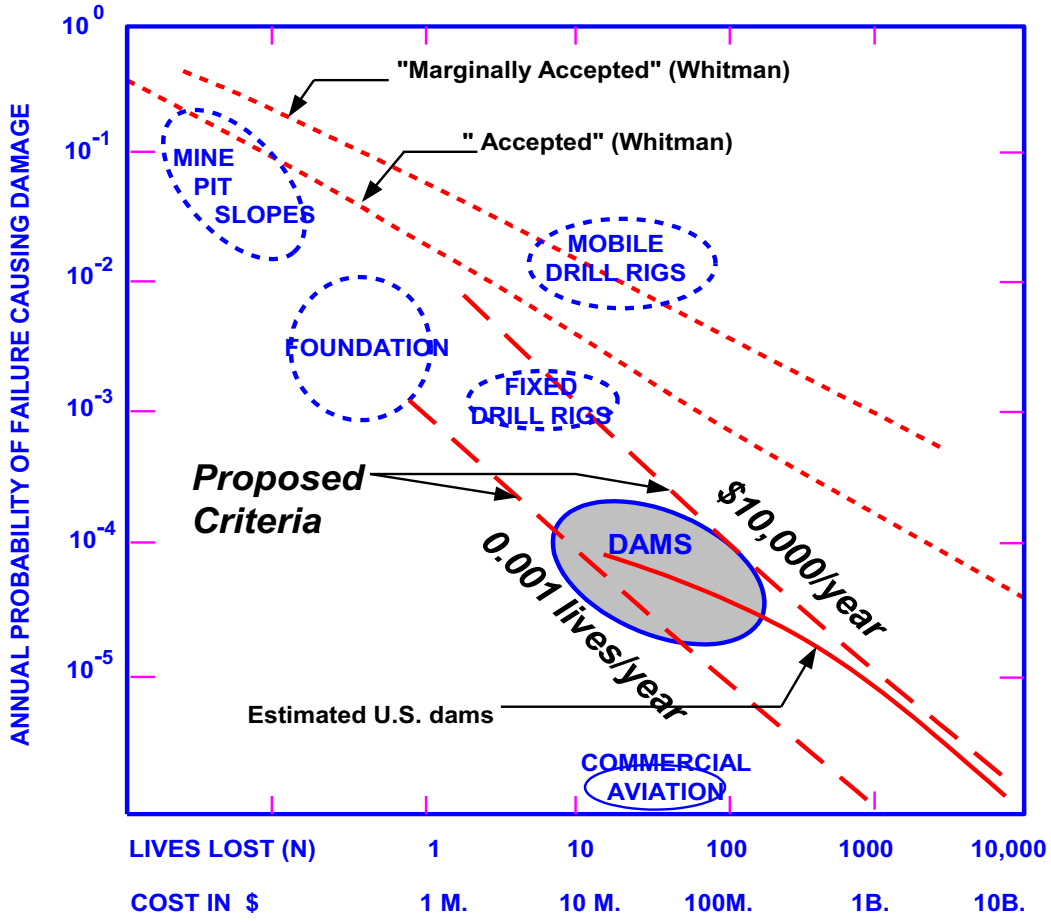
Definition

Risk is a product of the likelihood (or probability) of failure and the amount of loss (Consequences) after the dam failed.

Risk = Probability x Consequences

Overall of the dams that were failed is about 1 in 10,000 (or 10^{-4}) per year.

Acceptable criteria for many engineering structures (Whitman, 1984)



Methodology - Risk-Informed Decision Making (RIDM)

Potential Failure Mode Identification

identify the site-specific credible potential failure modes

Risk Estimation

Identify initiating event and progression leading to failure, estimate impact of failure

Risk Evaluation

examining and judging the significance of risk

Risk Analysis

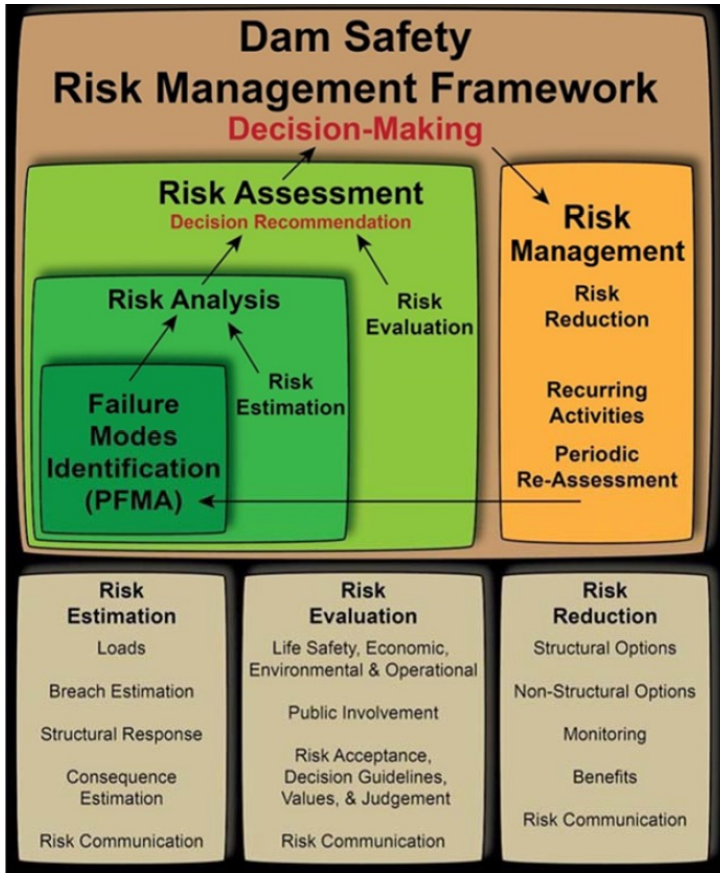
estimate the risk to individuals or populations, property or the environment, from hazards

Risk Assessment

process of making a decision recommendation on whether existing risks are tolerable and present risk control measures are adequate

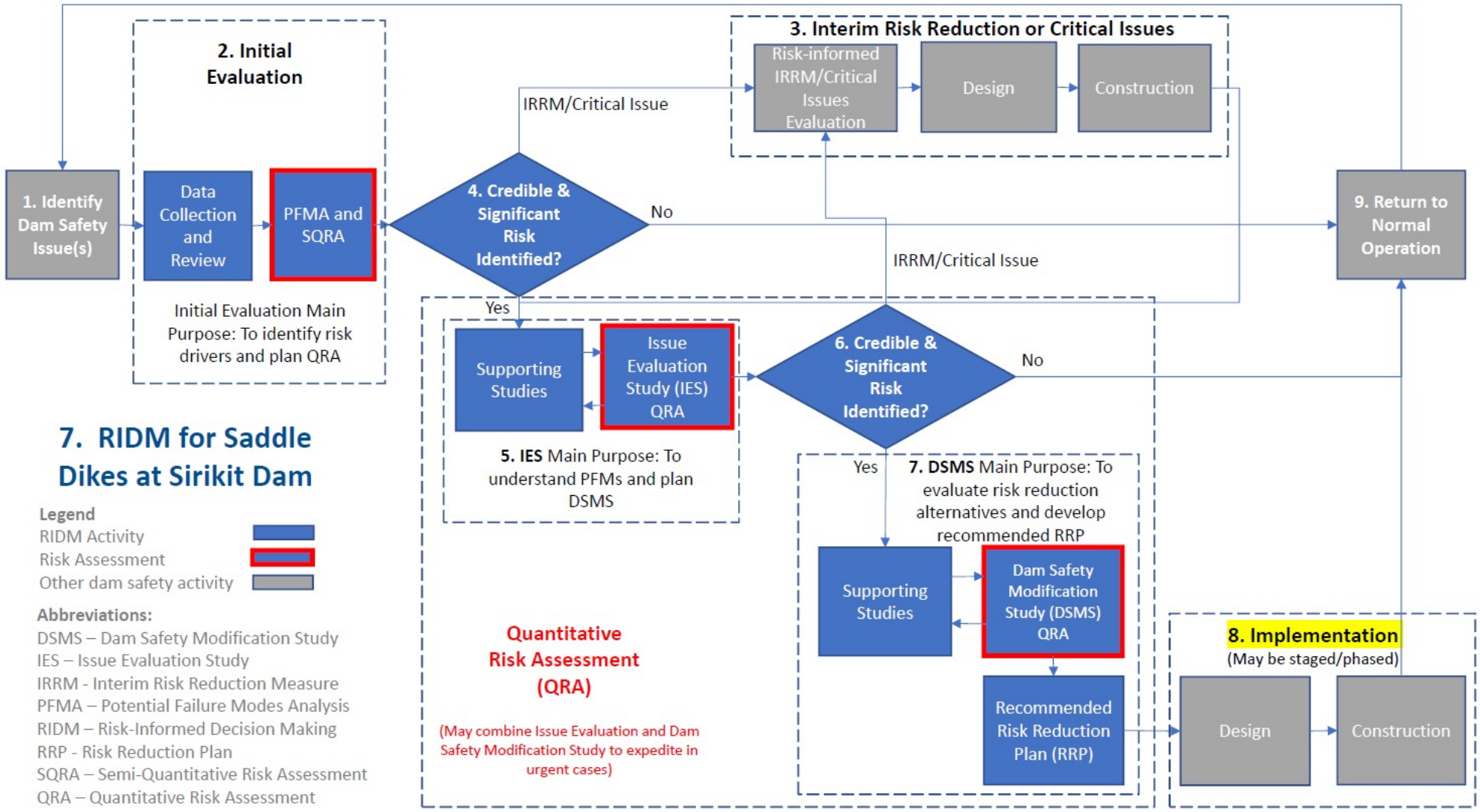
Risk Management

systematic application of management policies, procedures and practices to the tasks of identifying, analyzing, assessing, communicating, mitigating, and monitoring risk.



Source: Risk-informed Decision Making (RIDM) Risk Guidelines For Dam Safety, Federal Energy Regulatory Commission (FERC)

Application for dam risk analysis



Dam Risk Assessment Process

1. Data collection & review

- design records, construction history, hydrological/geological data, monitoring records, downstream exposure

2. Hazard & failure-mode identification

- credible failure scenarios under various load conditions (flood, seismic, aging)

3. Likelihood/Probability estimation

- determine how likely each failure mode could occur under defined scenarios

4. Consequence analysis

- estimate potential outcomes: loss of life, economic loss, infrastructure damage, downstream flooding, environmental/social impacts

5. Risk evaluation (Risk Matrix)

- combine likelihood and consequence to derive risk level; compare against safety thresholds or acceptable risk criteria

6. Risk Reduction Measures

- recommend structural remediation, maintenance, operational changes, monitoring/inspection schedule, emergency preparedness (warning systems, evacuation plans)

Potential Failure Mode (PFM)

PFM is a way that dam failure* can occur (i.e., the full sequence of events from initiation to failure) for a given loading condition.

*an uncontrolled release of the reservoir FEMA (2015), Federal Guidelines for Dam Safety Risk Management.



Dam Overtopping



Piping or Internal Erosion



Slope Instability

Potential Failure Mode (PFM) - PFM Survey

Original PFM # in field manual	PFM# including adjustment during PFMA	PFM Title
PFM ID-1-SD 1	PFM 1	Instability induced by Earthquake loads
PFM ID-2-SD 2	PFM 2	Internal Erosion (CLE) through embankment, crack induced by differential settlement between residual soil and embankment. This was clarified and modified during the PFMA to mean CLE along the Outlet Works in Dike 2
PFM ID-3-SD 2	PFM 3	Internal erosion (CLE and Contact Erosion) through pervious layer, crack, or defect in the dam foundation
PFM ID-4-SD 4	PFM 4	Backward erosion piping in foundation
PFM ID-5-SD 5	PFM 5	Internal erosion (CLE) initiated by Hydraulic Fracturing (HF)
PFM ID-6-SD 1,3,4,5,6,7,8 and SPLW	PFM 6	Overwash
PFM ID-7-SD 1,3,4,5,6,7,8 and SPLW	PFM 7	Overtopping after gates not opened after Earthquake
PFM ID-8-SD 1,2,3,4,5,6,7,8	PFM 8	Contact Erosion between residual soil and fracture rock foundation
PFM ID-9-SD 4	PFM 9	Deep seated downstream slope instability caused by the existing results of seepage/internal erosion through foundation - ID 9A Instability in Dike 4 at high reservoir water level - ID 9B Instability in maximum section of Dike 2 - ID 9C Slope Instability in Dike 2 near right abutment at high reservoir water level - ID 9D Instability in maximum section of Dike 1
PFM ID-10-SD 4		Instability of embankment - Duplicate
PFM ID-11-SD4	PFM 10	Instability of embankment
PFM ID-13-SD 1,3,4,5,6,7,8	PFM 11	Operation Induced Overtopping
PFM ID-12-SD 4	PFM 12	Internal Erosion (CLE) though embankment (excluding along outlet tunnel)
PFM ID-14-SPLW	PFM 13	Cavitation of spillway tunnels
-	PFM 14	Leak in the Outlet in dike 2
-	PFM 15	Unmapped faults below any one of the dikes
-	PFM 16	Debris blocking the spillway
-	PFM 17	Rapid draw down (RDD)
-	PFM 18	Unmapped faults and internal erosion
-	PFM 19	Seismic slope stability - 19A Seismic Instability (19A applies to all Dikes except Dike 4) - 19B Seismic Instability of Dike #4

PFM Survey - geology, dam safety, seismicity









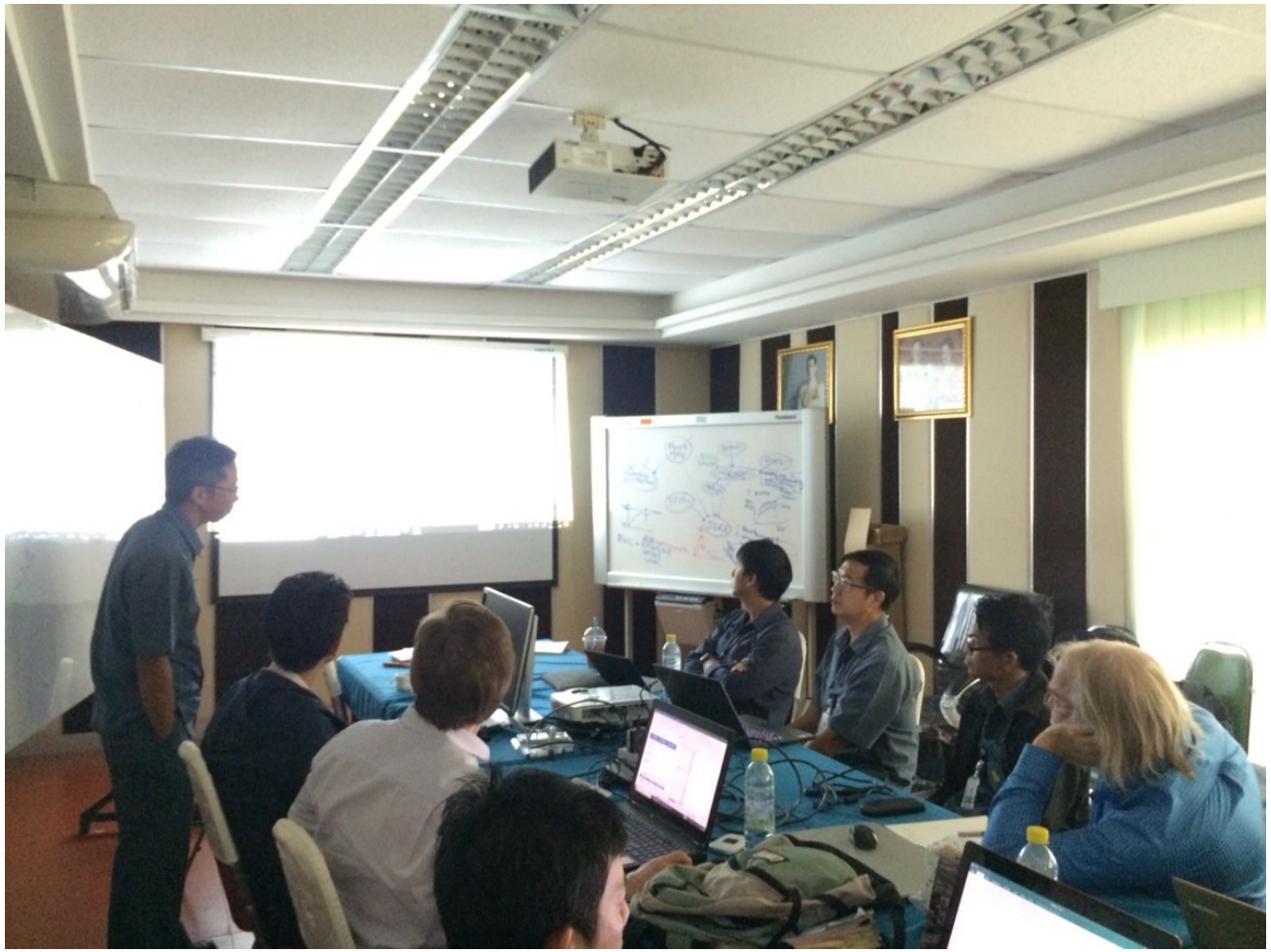




PFM Survey (Hydrology)







PFM Survey – Document Review & Discussion



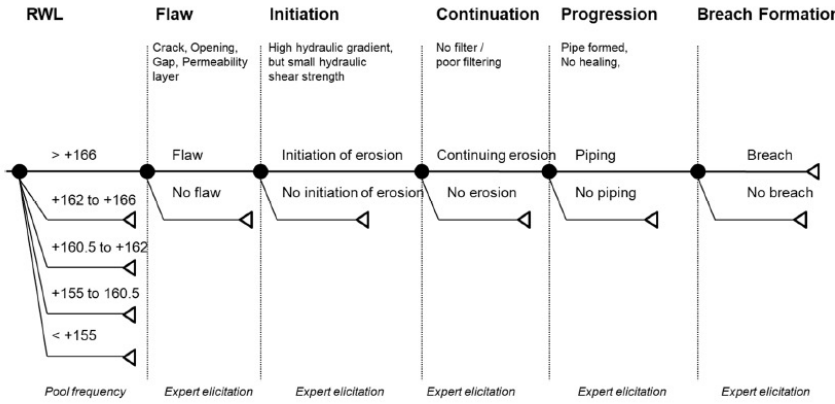


Credible and Significant PFMs for SQRA

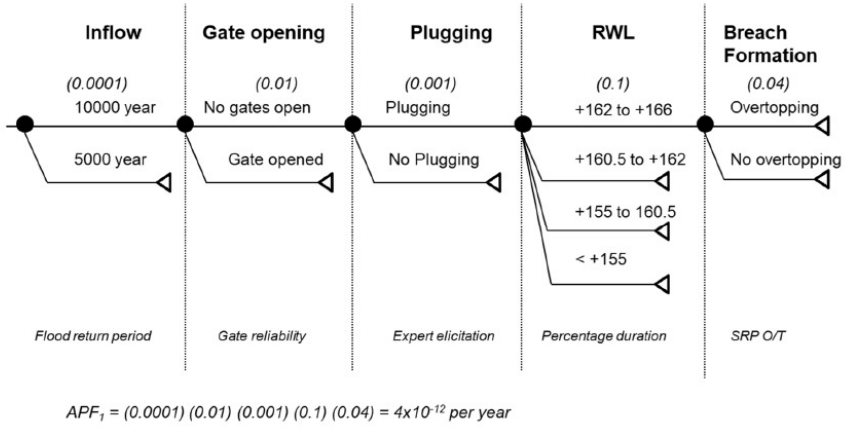
No	Failure mode	PFM Number	Combine PFM	Title
1	Internal Erosion	2	14	Seepage erosion along outlet
2	Internal Erosion	3	5,8,18	Contact erosion and scour
3	Overtopping and overwash	6	7,11,16	Overtop/overwash due to failure of spillway gates to open during a flood
4	Slope Stability	9A	-	Instability
5	Internal Erosion	12	-	Concentrated leak erosion though a flaw in the embankment
6	Slope Stability	19B	-	Seismic instability

Likelihood/Probability Estimation by Event Tree Analysis

1. Piping

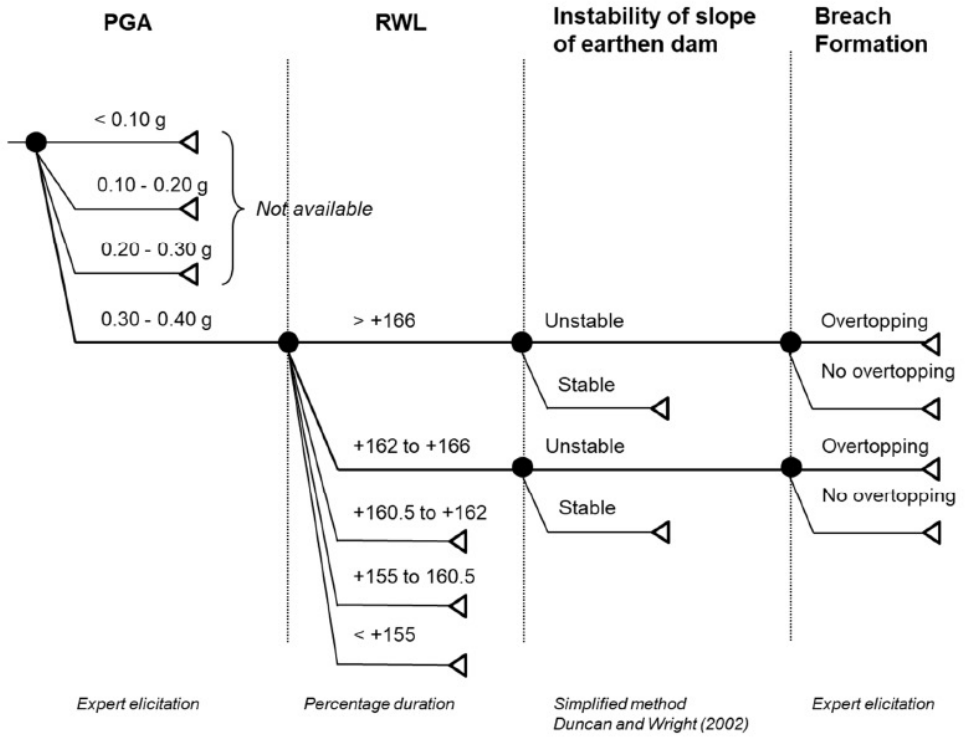


2. Flood

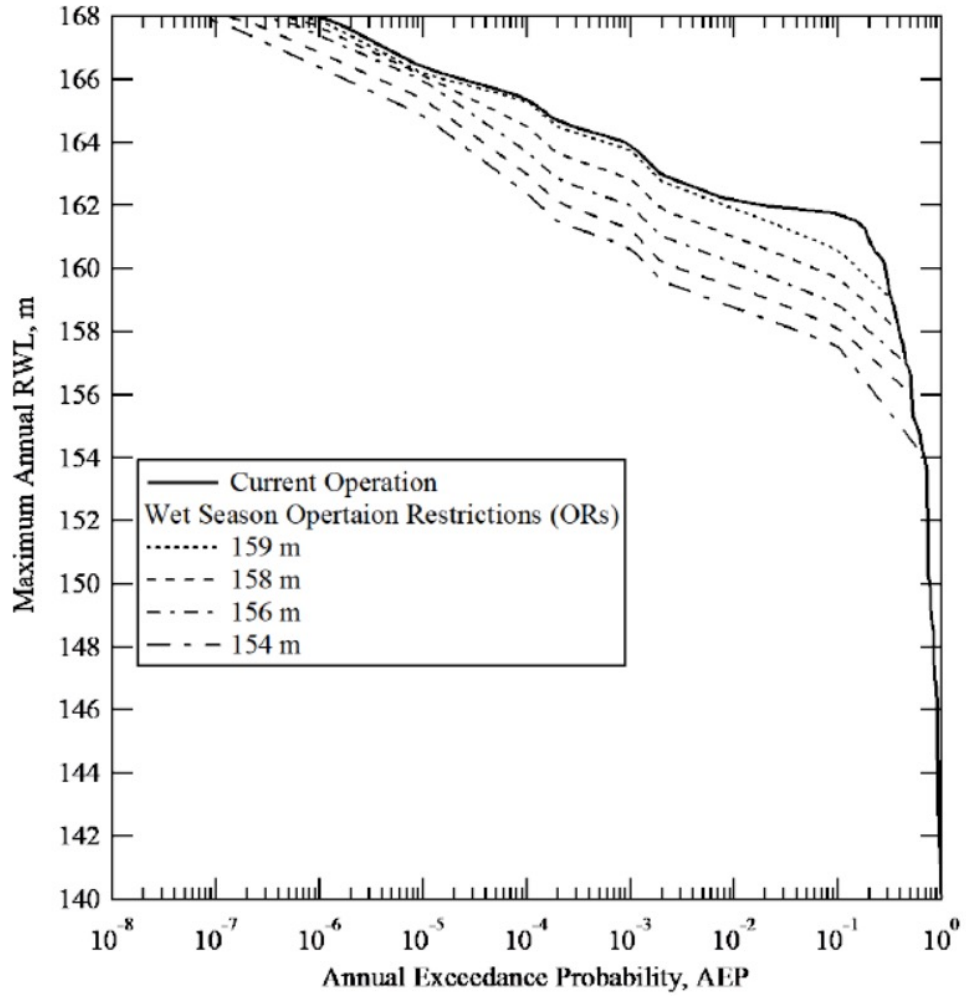


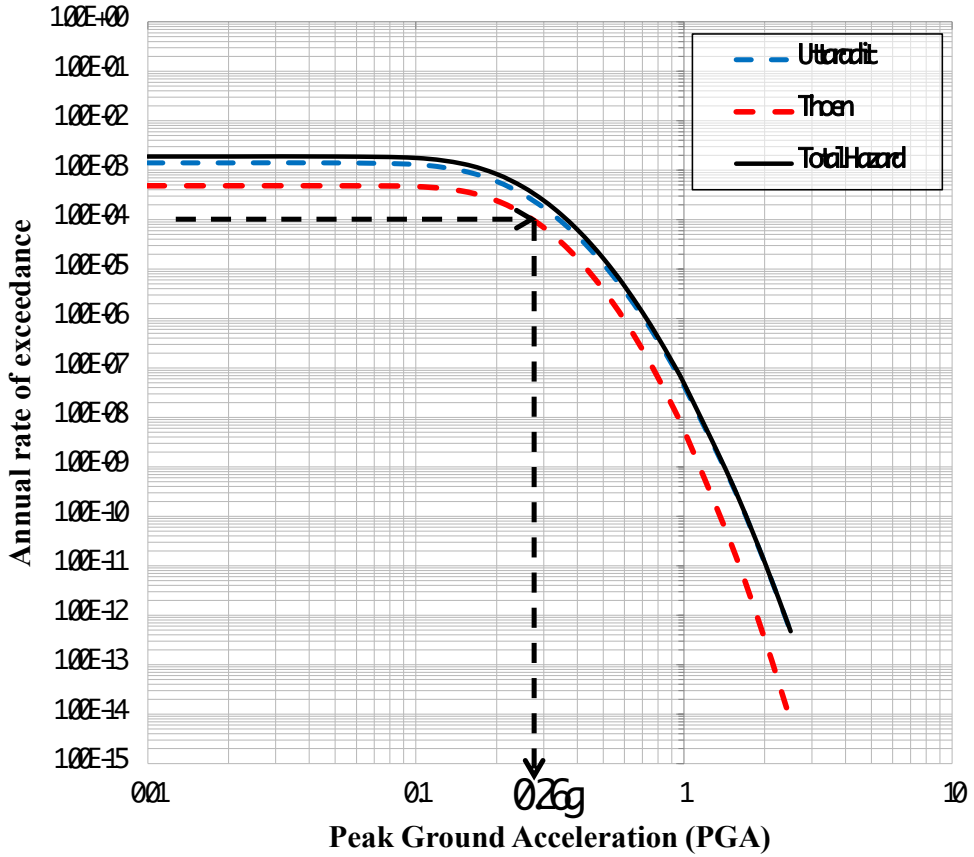
APF_1 = (0.0001) (0.01) (0.001) (0.1) (0.04) = $4x10^{-12}$ per year

3. Earthquake



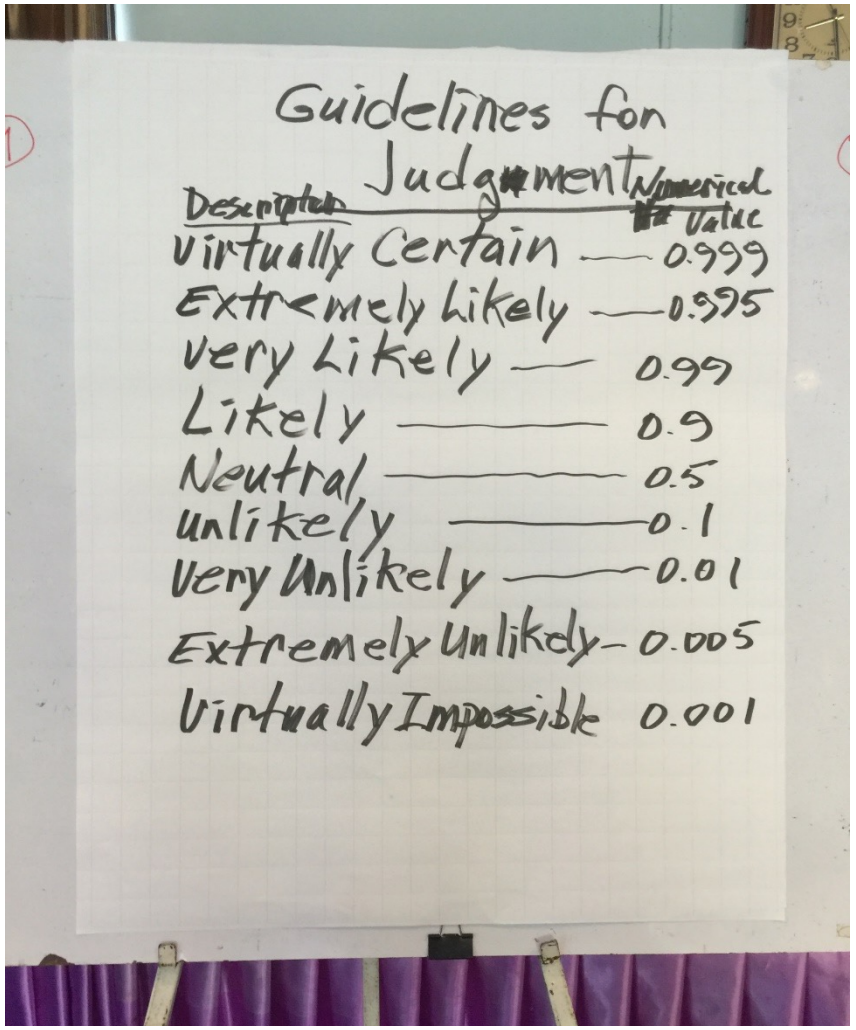
Annual Exceedance Probability (AEP) in each giving load





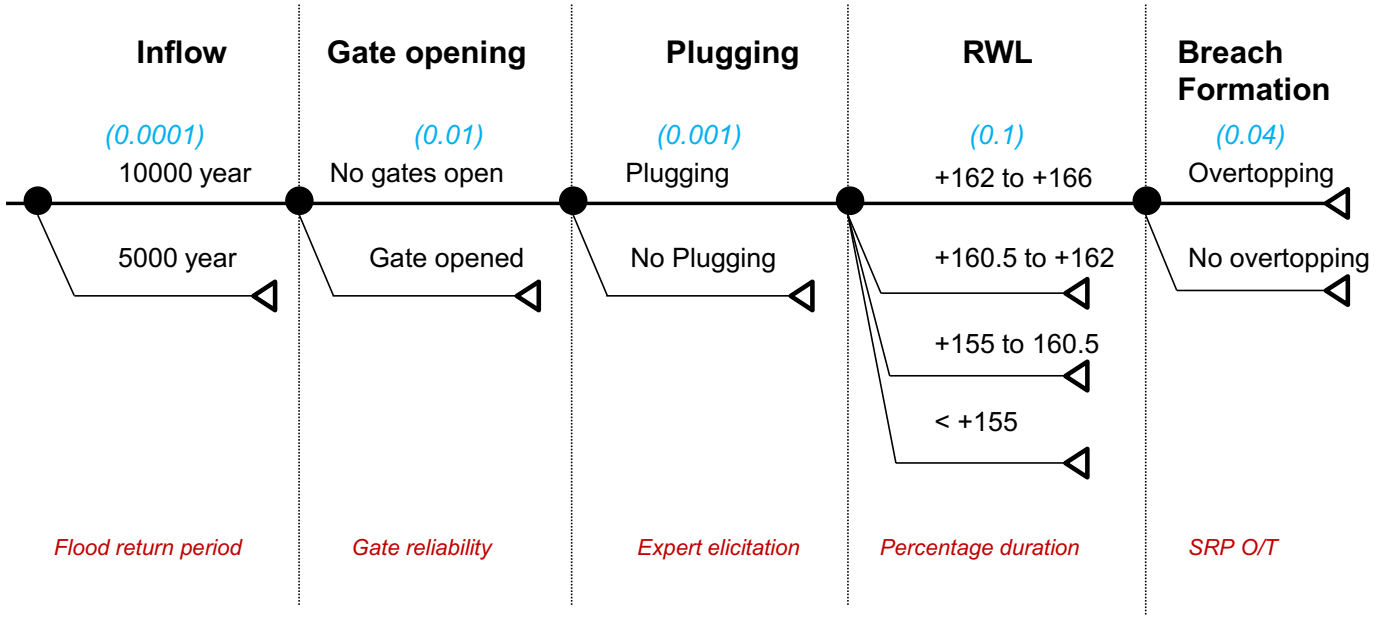
Judgment from Expert Opinion





Example of Annual Probability of Failure

Overtopping due to no gate opening



$APF_1 = (0.0001)\ (0.01)\ (0.001)\ (0.1)\ (0.04) = 4x10^{-12}$ per year

Example of Annual Probability of Failure

Event tree slope instability

RWL	Slope	Breach
162-166	Failed	Breach
160-162	No failed	No breach
155-160		

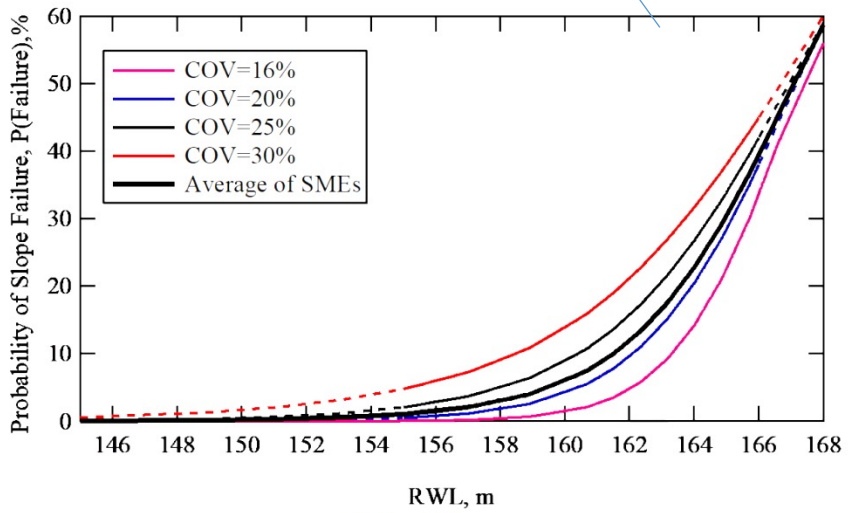


Figure 3. Probability of Slope Failure vs RWL

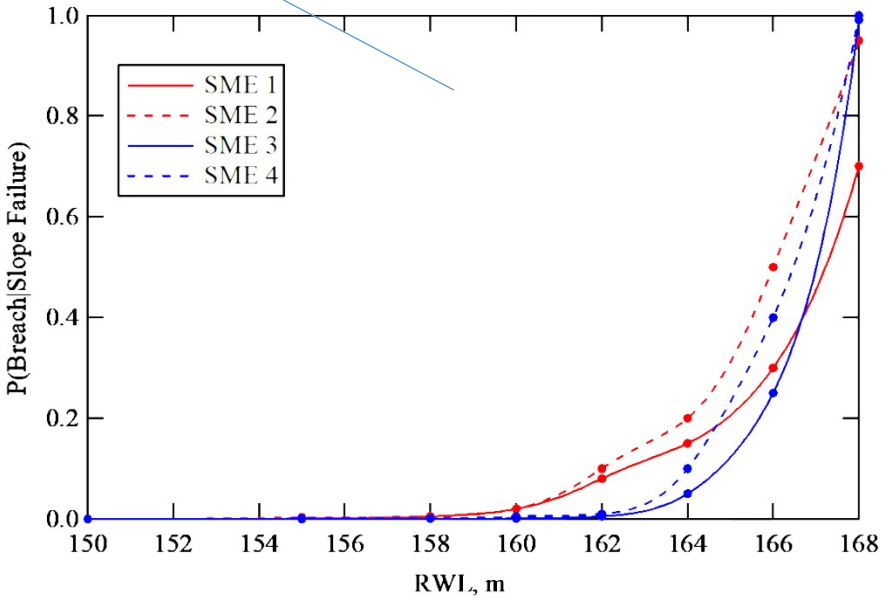
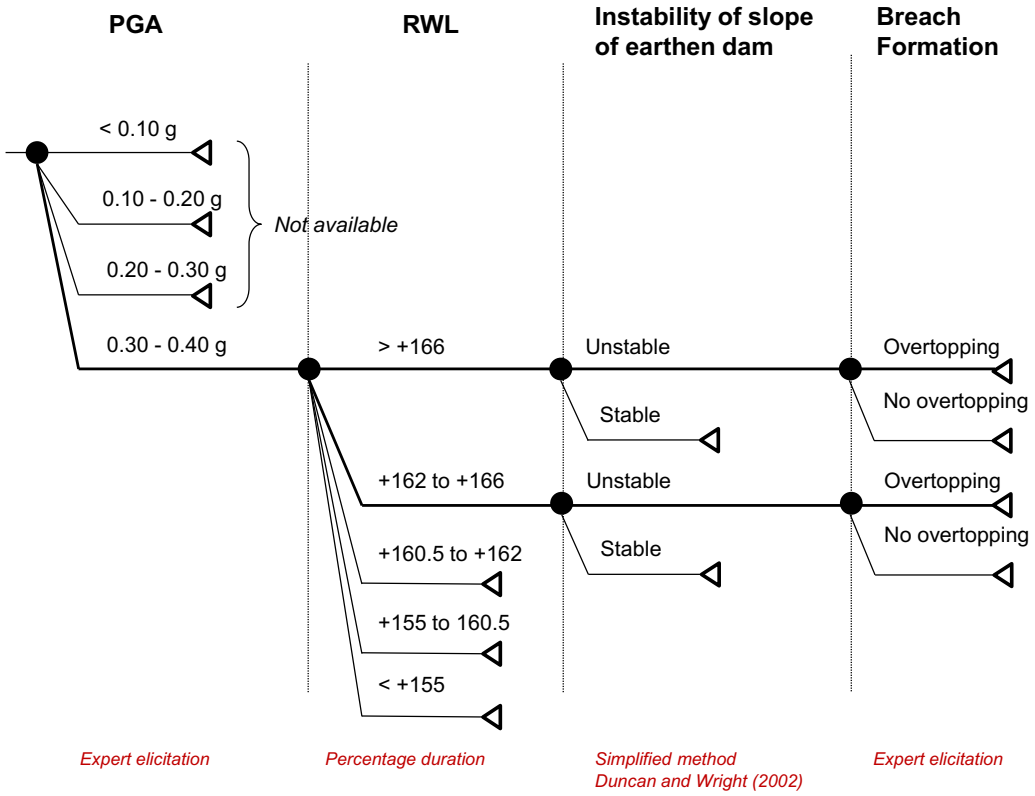


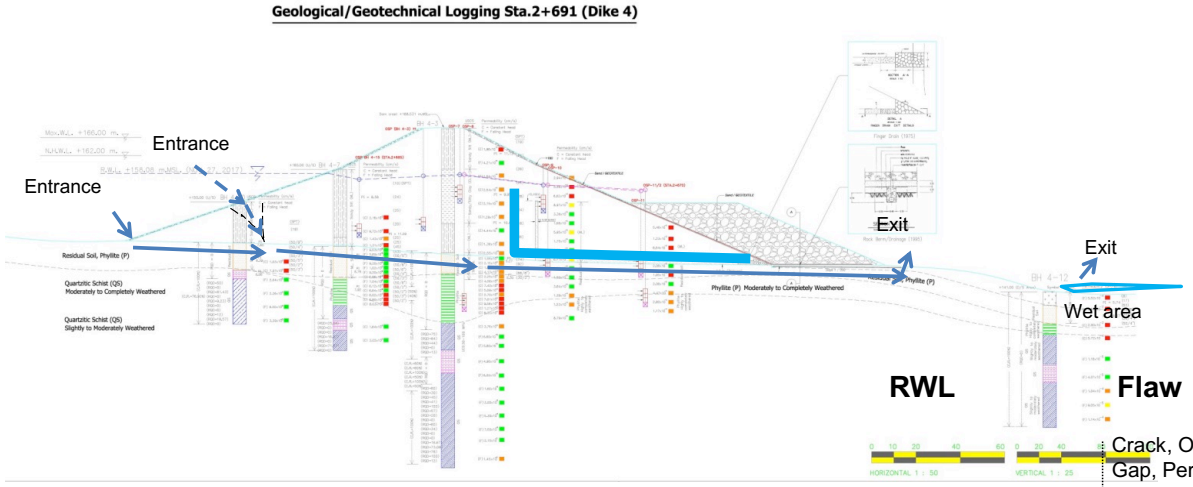
Figure 4. Estimates of P(Breach | Slope Failure) for the 4 SMEs

Example of Annual Probability of Failure

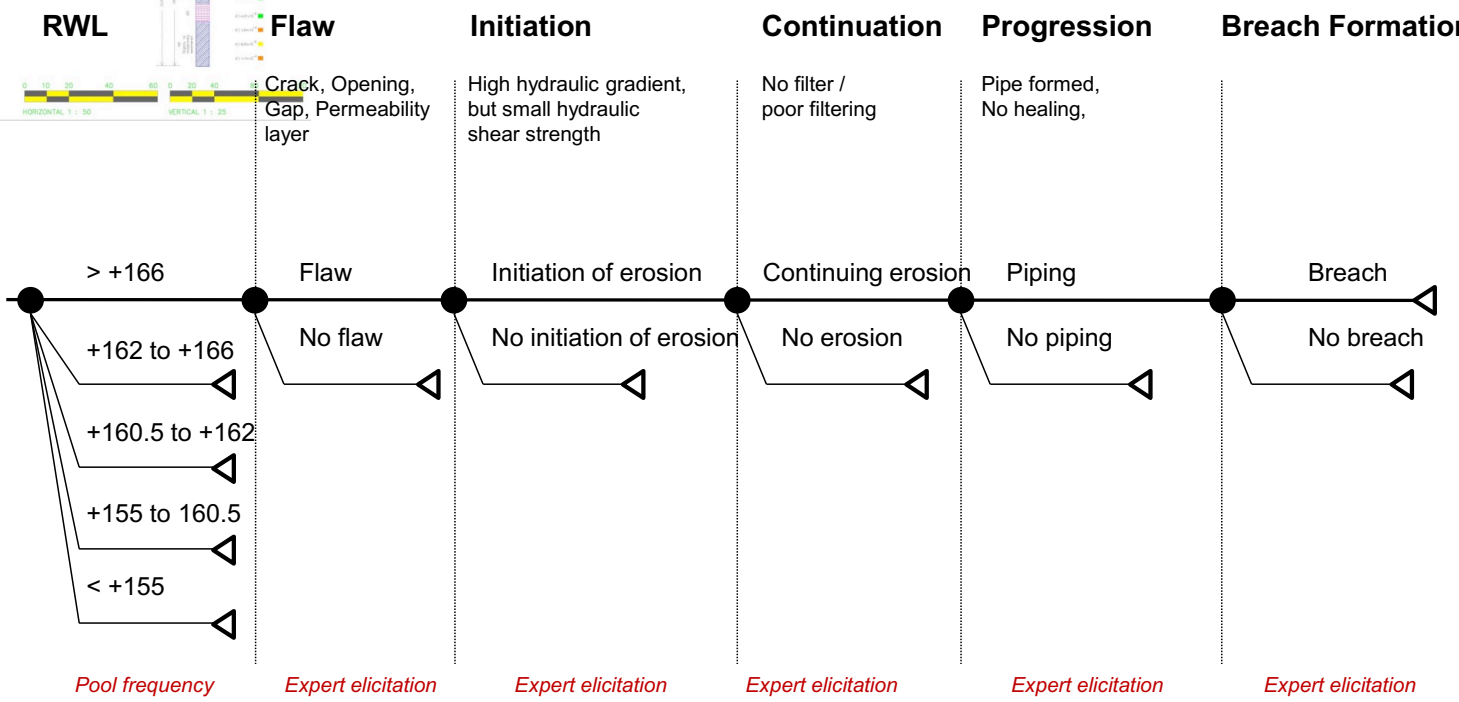
Overtopping due to earthquake



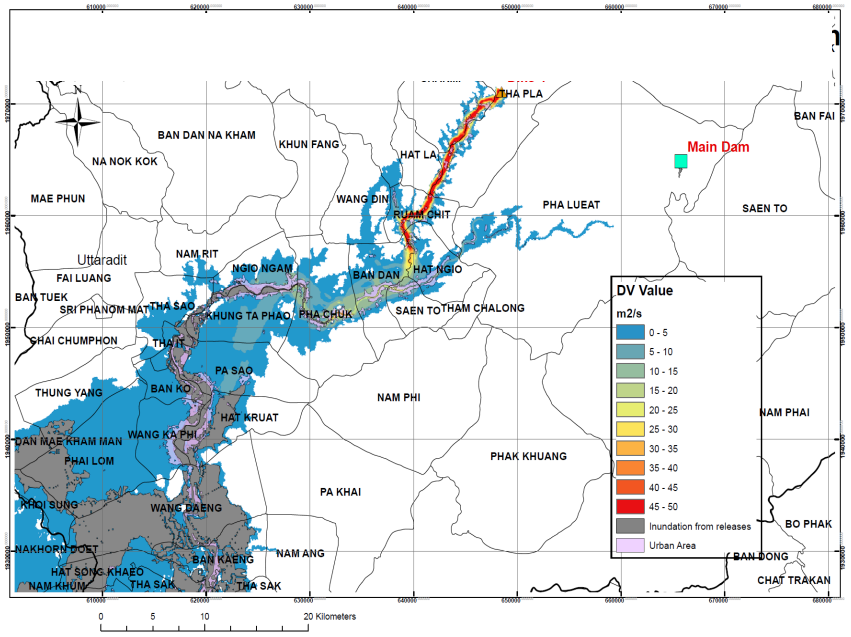
Example of Annual Probability of Failure

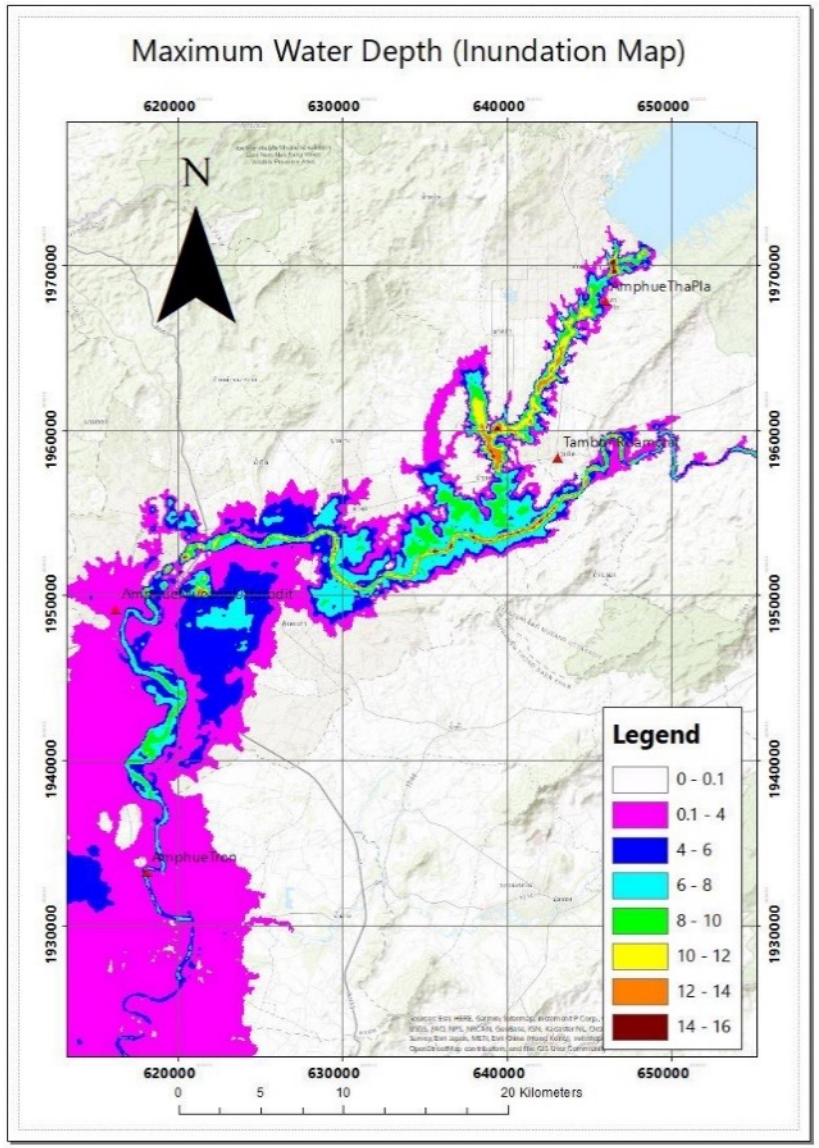


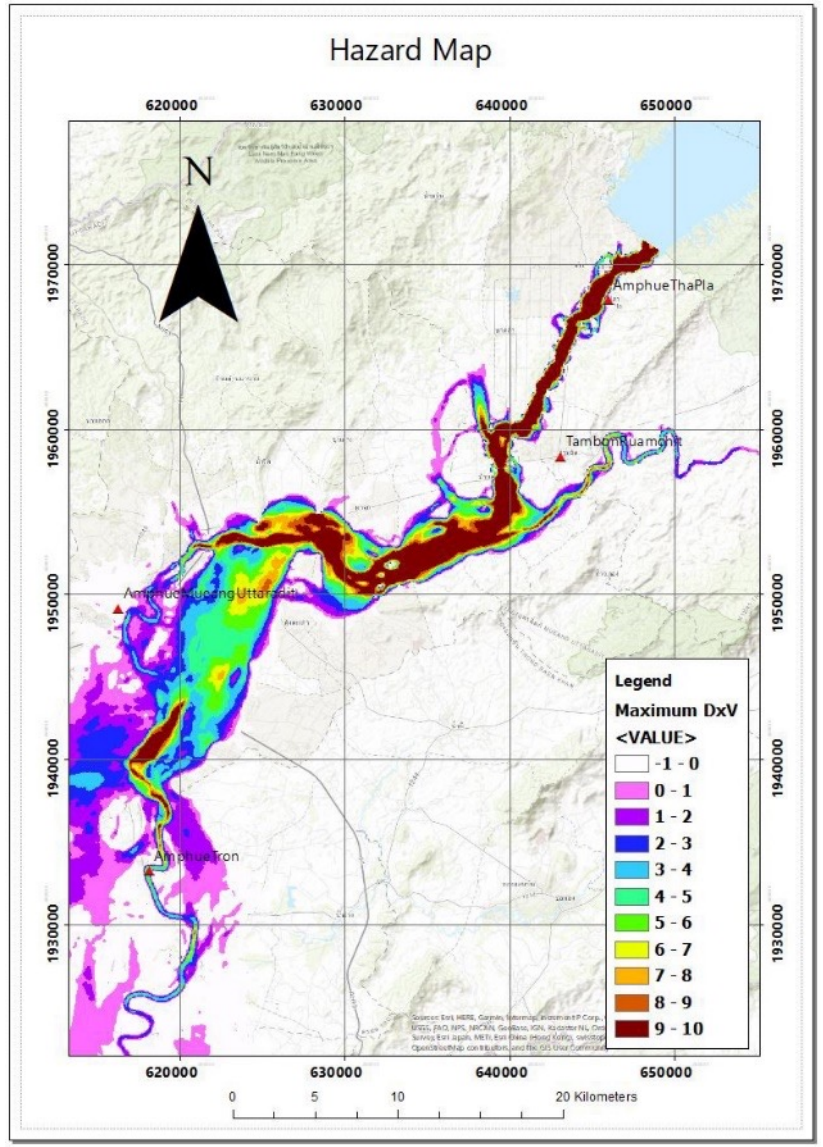
Concentrated leak erosion though a flaw in the embankment



Consequence analysis - Inundation area

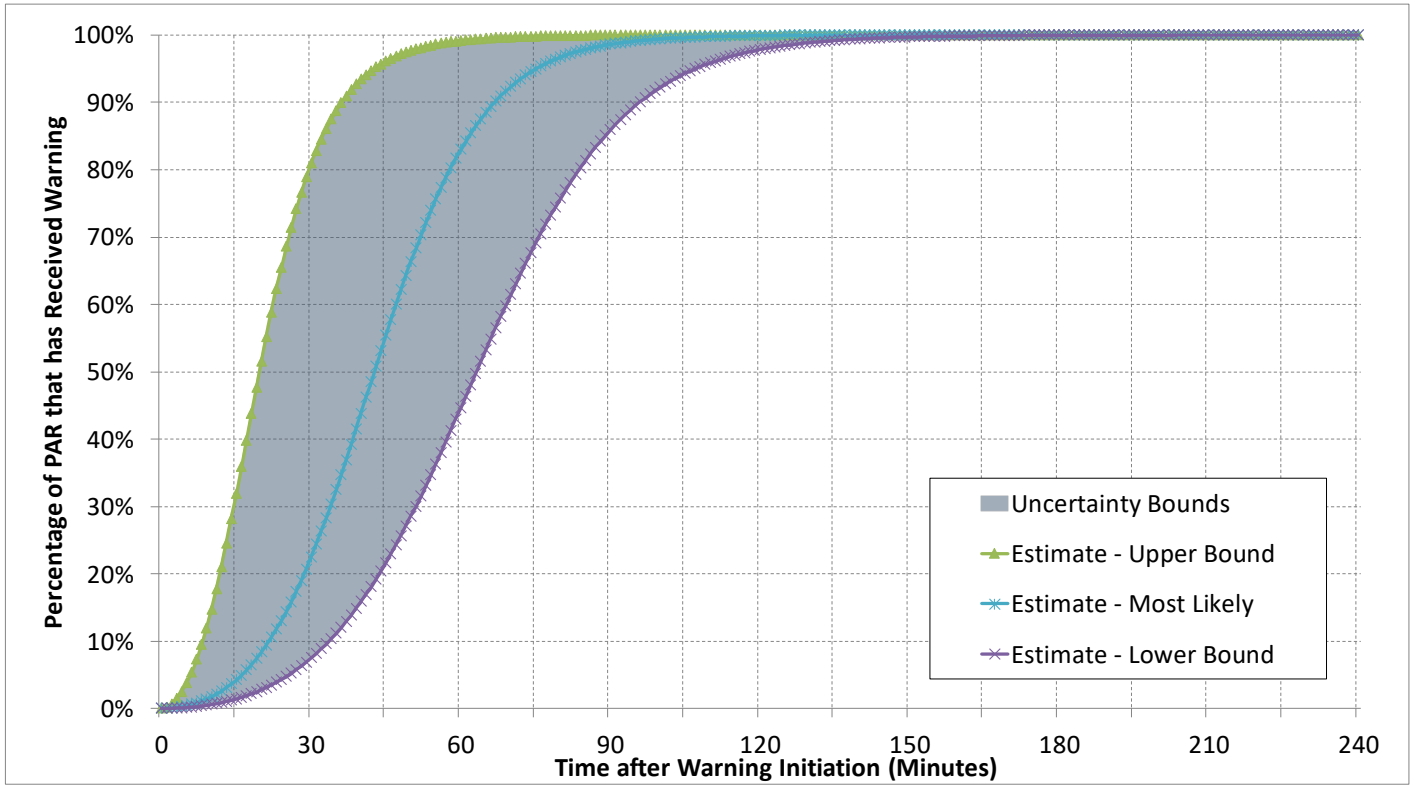




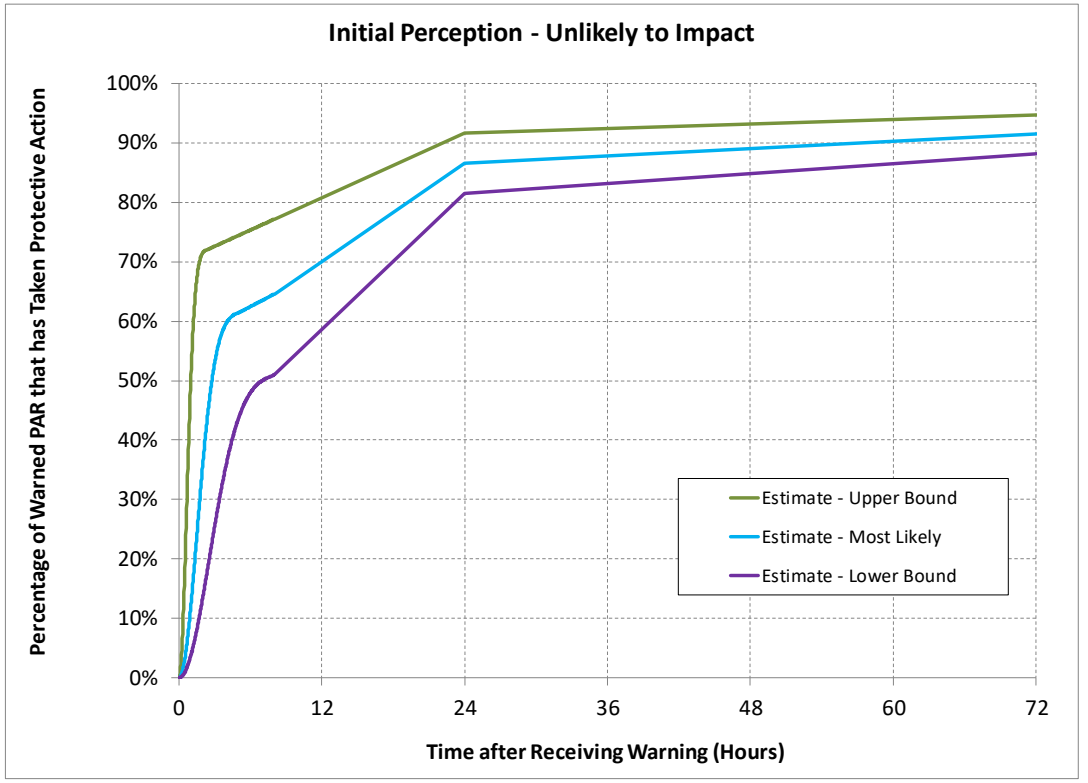


Warning Diffusion & Mobilization curve

Warning Diffusion curve



Mobilization curve

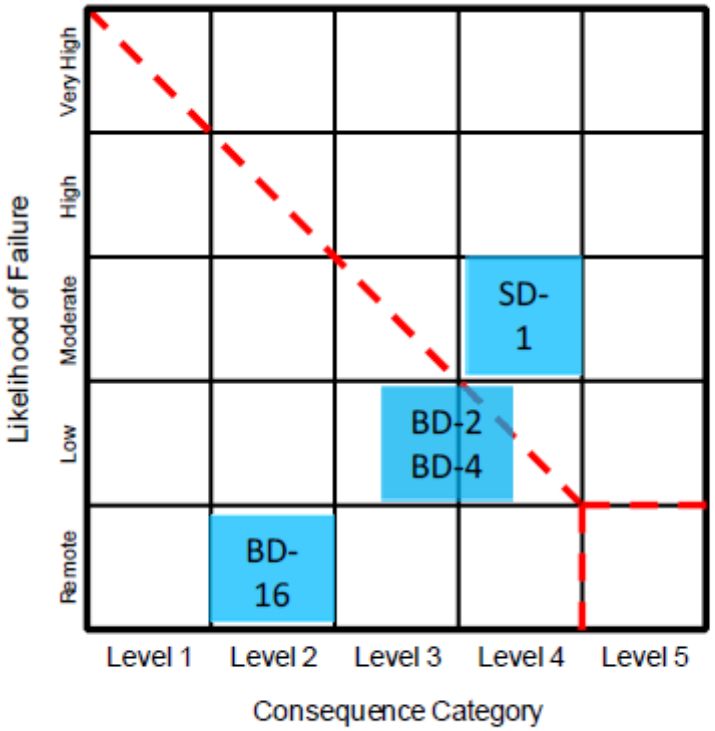


Consequence Level

PFM #	PFM Description	Consequence Level					
		Level 1	Level 2	Level 3	Level 4	Level 5	Level 6
		Incremental Life Loss					
		0 - 1	1 - 10	10 - 100	100 - 1,000	1,000 - 10,000	> 10,000
2	Seepage erosion along dike 2 outlet	0.00	0.00	0.00	0.03	**0.97**	0.00
3	Contact erosion and scour	0.00	0.00	0.00	0.03	**0.97**	0.00
6	Overtop Overwash due to flooding and failure of gates	0.00	0.00	0.00	**0.56**	0.44	0.00
9A	Instability of Dike 4	0.00	0.00	0.00	0.00	**0.65**	0.35
12	Concentrated Leak Erosion though a flaw in the embankment	0.00	0.00	0.00	0.03	**0.96**	0.01
19B	Seismic Instability	0.00	0.00	0.00	0.03	**0.97**	0.00

Risk evaluation by Risk Matrix

1. PFMA
2. ETA (Event Tree Analysis)
3. Judgment

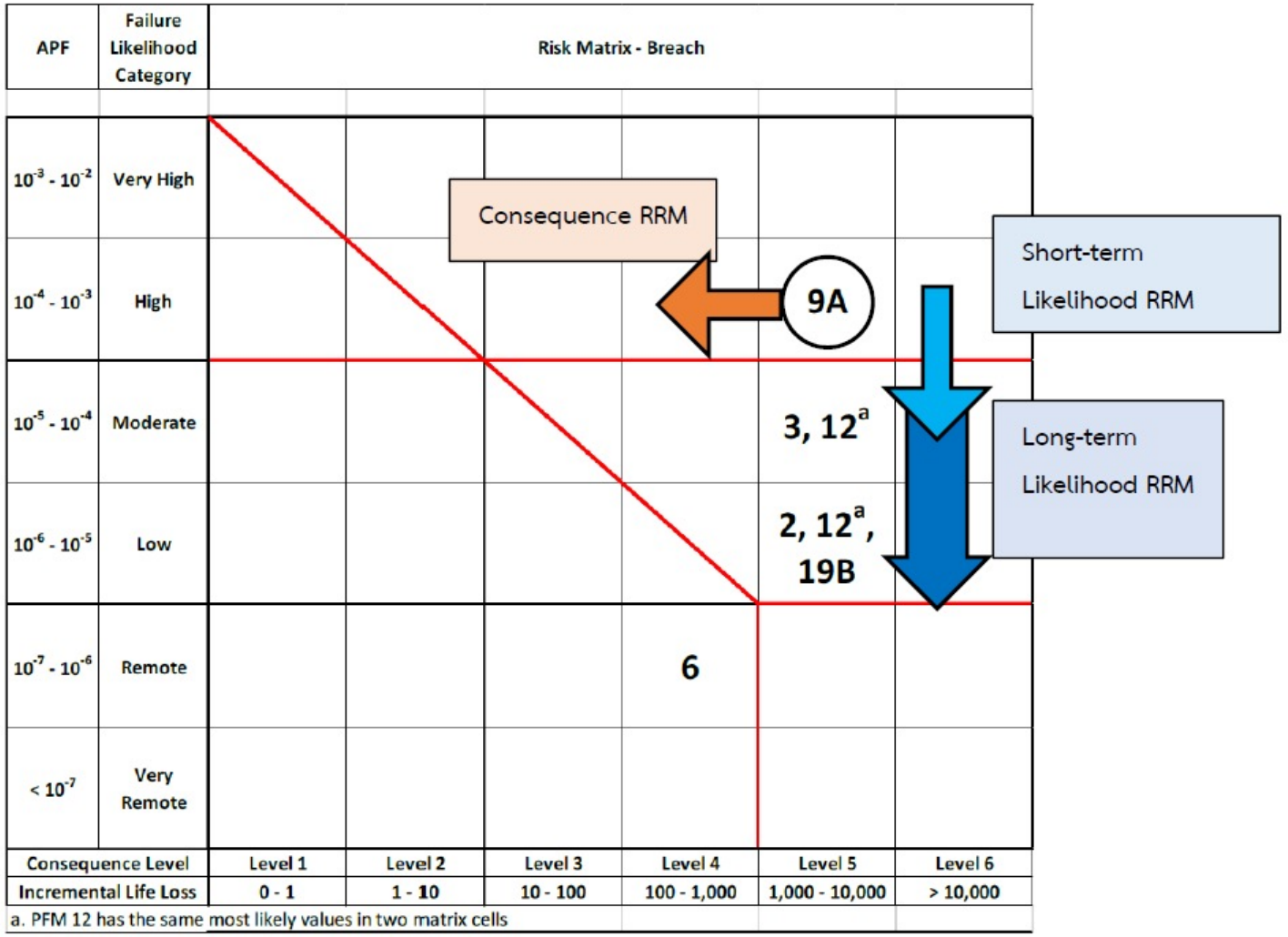


Risk-Driver PFMs

PFM BD-2: Backward Erosion Piping through the Main Embankment Foundation Material.
PFM BD-4: Concentrated Leak Erosion (Scour) along the Main Embankment Outlet Conduit.
PFM BD-16: Seismically Induced Cracks through the Main Embankment.
PFM SD-1: Concentrated Leak Erosion (Scour) along the Saddle Dike Conduits.

3. LOL estimation
2. Inundation area
1. Dam break analysis

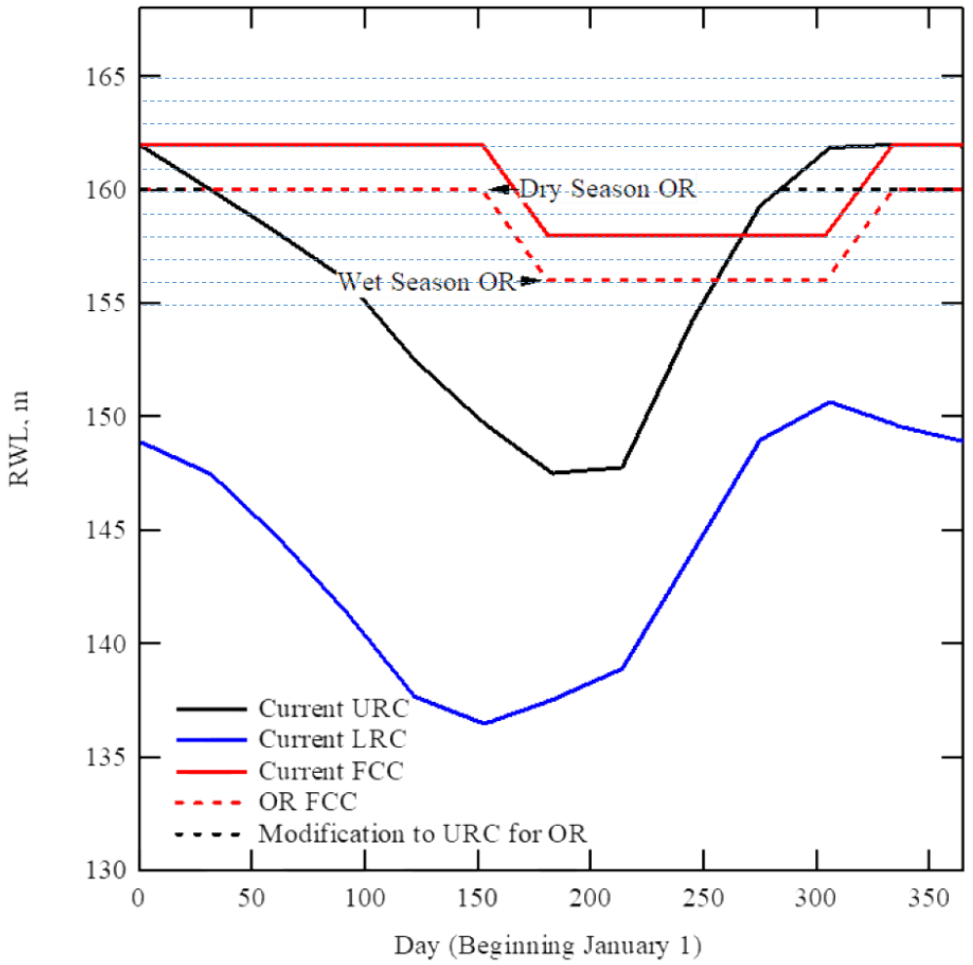
Risk Reduction Measures (RRM)



APF	Failure Likelihood Category	Risk Matrix - Breach					
10^{-3} - 10^{-2}	Very High						
10^{-4} - 10^{-3}	High					9A	
10^{-5} - 10^{-4}	Moderate					3, 12[a]	
10^{-6} - 10^{-5}	Low					2, 12[a], 19B	
10^{-7} - 10^{-6}	Remote				6		
< 10^{-7}	Very Remote						
Consequence Level		Level 1	Level 2	Level 3	Level 4	Level 5	Level 6
Incremental Life Loss		0 - 1	1 - 10	10 - 100	100 - 1,000	1,000 - 10,000	> 10,000

a. PFM 12 has the same most likely values in two matrix cells

Interim Risk Reduction Measures (IRRM)

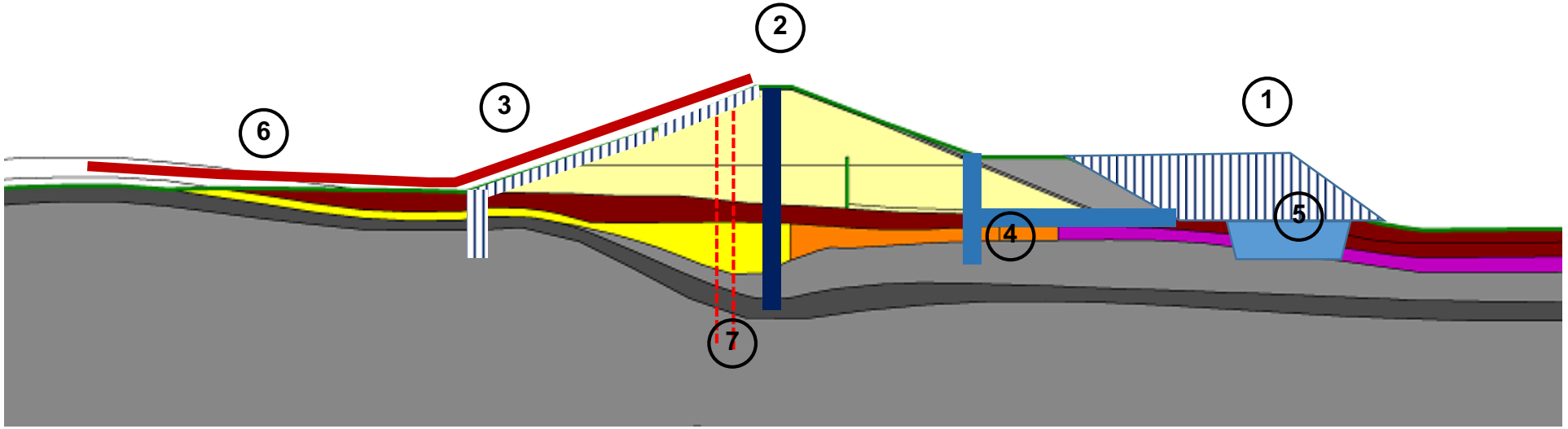


- Reservoir Operating Restriction
- Review the Emergency Action Plan
- Review Flood control curve
- Dam Surveillance
- Stock Pile Material

Risk Reduction Measures (RRM)

Several alternatives to mitigated against the instability of slope

1. Enlarge Downstream Stability Berm
2. Cutoff Wall from Dam Crest
3. Cutoff wall at upstream toe with blanket on upstream face
4. Relief Wells
5. Relief Trench
6. Upstream seepage blanket
7. Grouting upstream of dam crest

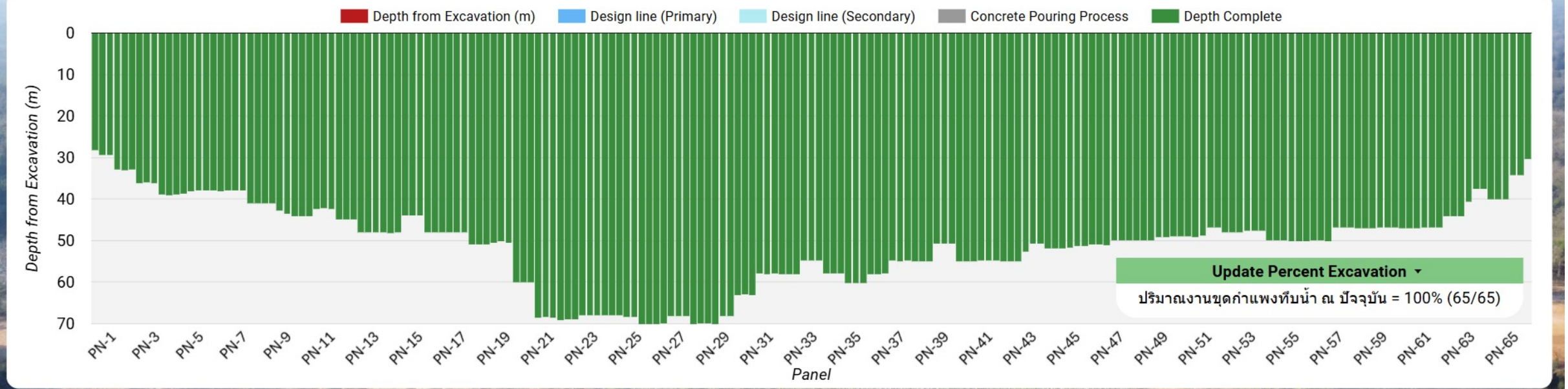


RRM - Rehabilitation of Sirikit Saddle Dam Dike 4

Plastic Concrete Cutoff Wall

EGAT KU KASETSART UNIVERSITY KAMPHAENG SAEN CAMPUS

Concrete Pouring | Lab Test | Excavation Panel | Back



Panel	Status	Start of Excav.	End of Excav.	Duration of Excav.	Depth Bite1	Depth Bite3	Depth Bite2	Backfill Date	Mix Use	Duration Backfill	Concrete age	Theory Concrete (Echo)	Request Concrete	Actual Concrete volume
D4CW-12	Complete	28/06/25	06/07/25	7 day	45.06	45.08	45.02	12/07/25	Mix 3+2	8.59 hr.	28 day	307.43	-	310.30
D4CW-26	Complete	26/06/25	09/07/25	12 day	70.18	70.77	70.06	09/07/25	Mix 3+2	17.19 hr.	31 day	513.92	-	503.82
D4CW-32	Complete	19/06/25	28/06/25	10 day	58.10	58.08	58.10	30/06/25	Mix 3+2	10.49 hr.	40 day	392.36	-	399.60

RRM - Rehabilitation of Sirikit Saddle Dam Dike 4

Plastic Concrete Cutoff Wall





RRM - Rehabilitation of Sirikit Saddle Dam Dike 4

Plastic Concrete Cutoff Wall







Conclusion

1. Dam safety review is very importance to know the status (or healthy) of dams. And it's a first screening information for Risk Assessment.
2. Dam risk assessment is essential for safety, planning, and decision-making.
3. A systematic approach helps identify high-priority risks.
4. Monitoring, Risk Reduction Measures, and strong emergency plans can reduce risks.

EGAT

Thank You

www.egat.co.th

EGAT



Mr.Montri Jinagoolwipat

Head, Dam Safety Analysis Section

Civil Maintenance Division

Sai Noi Office

Electricity Generating Authority of Thailand

81 Moo 11 Bang Kruai-Sai Noi Sai Noi Sai Noi

Nonthaburi 11150

57216513

0613879955

montri.jin@egat.co.th

-