Risk Assessment for Flood Risk Management Studies

Geotechnical Aspects of Risk Assessment

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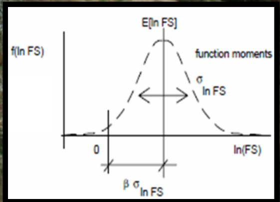

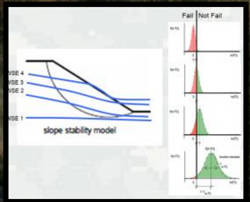

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Four Part Presentation

Part 1: What is Geotechnical Engineering

Part 2: Geotechnical engineering for planning studies

Part 3: Developing performance functions

Part 4: Trouble-shooting HEC-FDA results

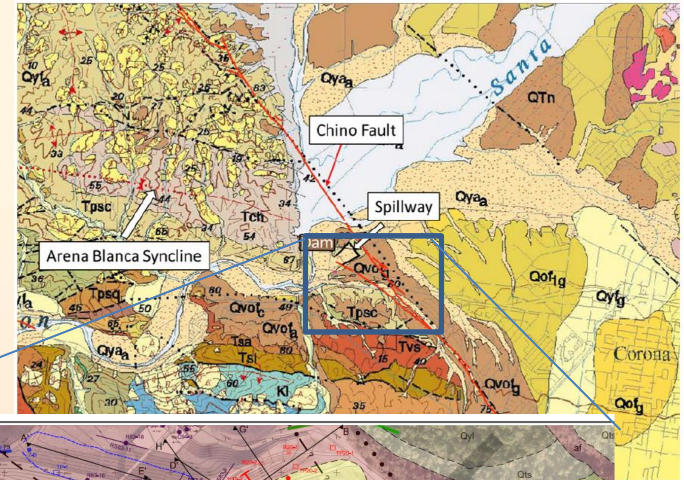
What is Geotechnical Engineering?

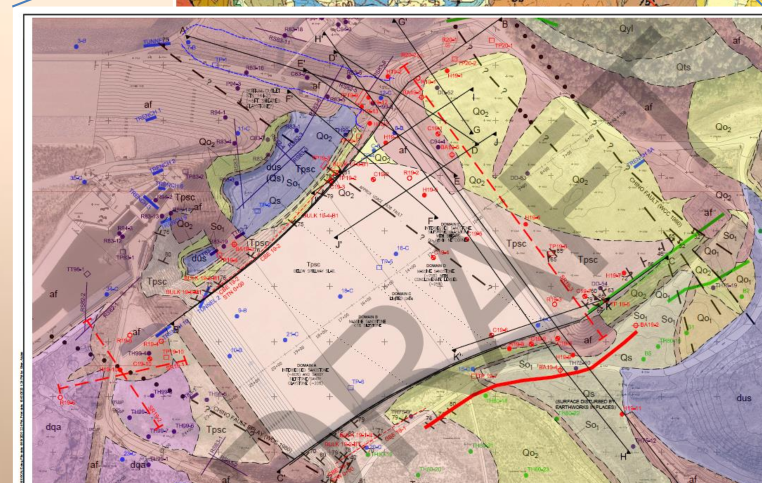
- **Geotechnical engineering:** a branch of civil engineering concerned with the engineering behavior of earth materials. It uses the principles and methods of geology, soil mechanics and rock mechanics for the solution of engineering problems and the design of engineering works.

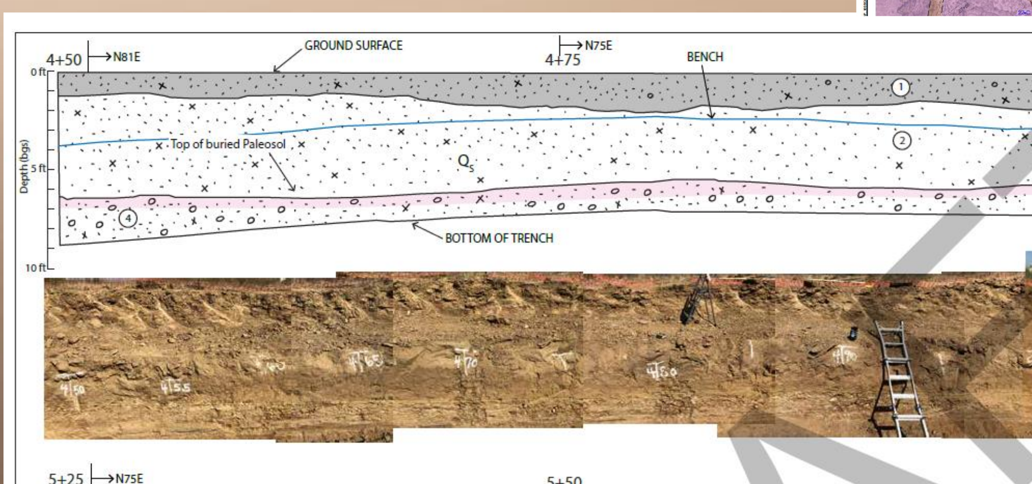
Geotechnical and Geologic Studies

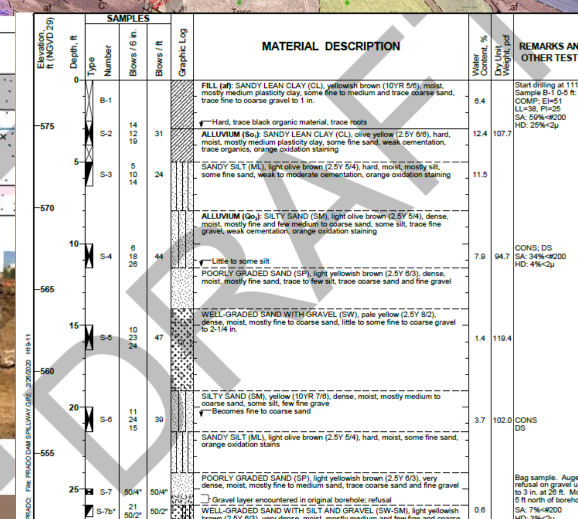
Understand the Geology

- Regional Geology
- Local Geology
- Site specific investigations

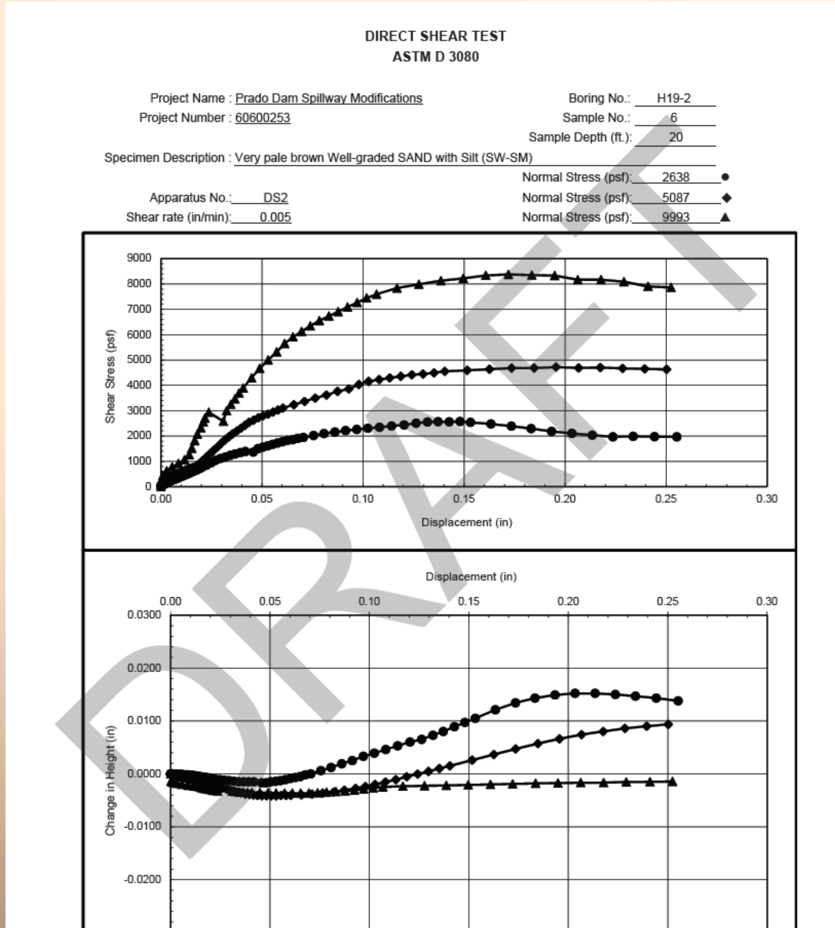








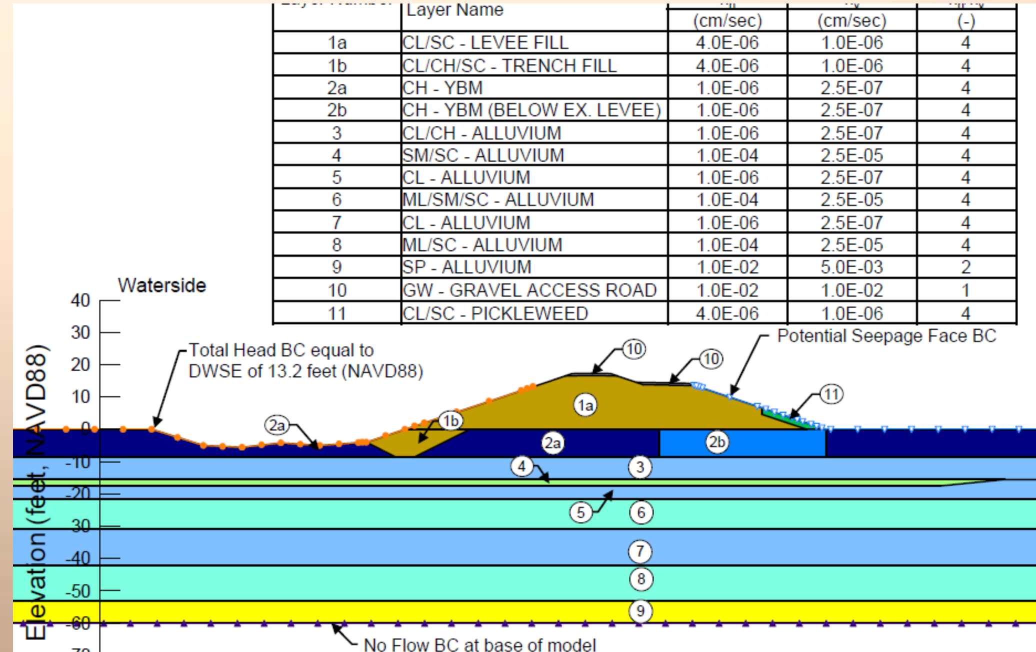
Laboratory Testing



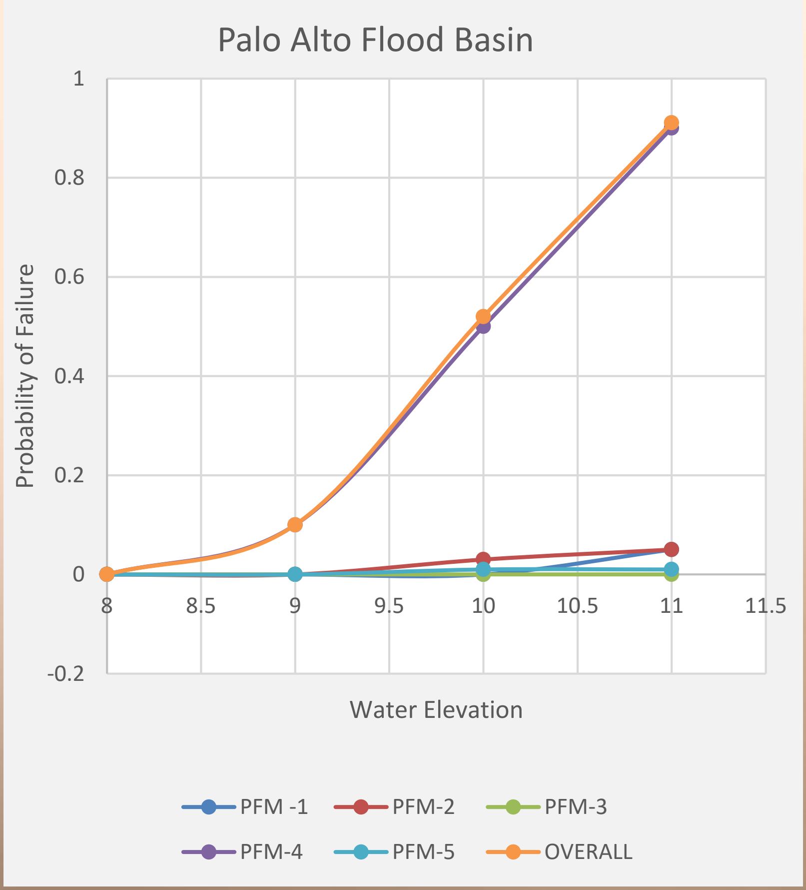
Types	Unit Weight (psf)	Drained Strength	Consolidation Properties	Saturated Hydraulic conductivity	Undrained Strength S_u (psf)
New Levee Fill	125	φ' = 32°; c' =100 or less	N/A–compacted, highly over consolidated	8x 10^{-6} cm/sec or lower	800
Existing Levee Fill Station 150 to 199	125	φ' = 32°; c' =100 or less	N/A–compacted, highly over consolidated	8x 10^{-6} cm/sec or lower	800
Desiccated Bay Mud Stations 95 to 144	100	φ' = 32°; c' =100 or less	Cc=1.22 (varies) Cr= 0.19(varies) OCR=2.5(varies)	8x10^{-7} cm/sec	Range from 130 to 270 psf based on stress history
Normally Consolidated YBM Station 95 to 144	100	φ' = 31°; c' =100 or less	Cc′=0.34 Cr′=0.05 OCR =1.1(varies)	8x10^{-7} cm/sec	Range from 250 to 360 psf
Overconsolidated Bay Mud (Reach 5) Station 144 to 199	100	φ' = 32°; c' = 100 or less	Cc=0.25 (varies) Cr= 0.09 (varies) OCR= TBD	8x10^{-7} cm/sec	1000
Clayey Alluvium	125	φ' = 32°; c' =100 100 or less	Cc= 0.23(varies) Cr = 0.06 (varies) OCR= 2 (varies)	1x10^{-6} cm/sec	2000
Sandy alluvium	125	φ' = 34°; c' = 0	N/A	2x10^{-3} cm/sec	N/A
Filter Sand	125	φ' = 34°; c' = 0	N/A	2x10^{-2} cm/sec	N/A
Gravel toe drain	135	φ' = 36°; c' = 0	N/A	1 cm/sec	N/A

Analysis

- Slope Stability
- Seepage
- Settlement
- Bearing Capacity
- Lateral Earth Pressures
- Filters
- Dewatering
- Pile Capacity
- Earthquake Ground Motions
- Liquefaction Potential



Evaluate Performance and Recommend Designs



	PED	Final Integrated Document
Alignment	Along with inboard, non-engineered dike of Pond A18	No change
Crest: Elevation	15.2 feet	No change
Crest: Width (typical)	16.0 feet	16.0 feet (minimum)
Crest: Width (turnout)	28.0 feet	Not defined
Crest: Cross Slope (from centerline)	3 percent	2 percent
Crest: Post-Construction Settlement	Varies, depending on location	Not defined
Slope	3H:1V (maximum)	No change
Slope: Erosion Project (bayward)	Reinforced turf mat to be covered by ecotone	Not defined
Slope: Erosion Protection (landward)	TBD	Not defined
Access Road: Material	Aggregate base (8 inches)	Aggregate Base
Access Road: Width (typical)	12 feet	Undefined
Access Road: Width (turnout)	26 feet	

Part 2 Outline: Geotechnical engineering for planning studies

- USACE policy and guidance
- Overtopping vs breach prior to overtopping
- Risk equation
- Performance function definition
- Geotechnical impacts to B/C ratio
- Level of effort for SMART Planning

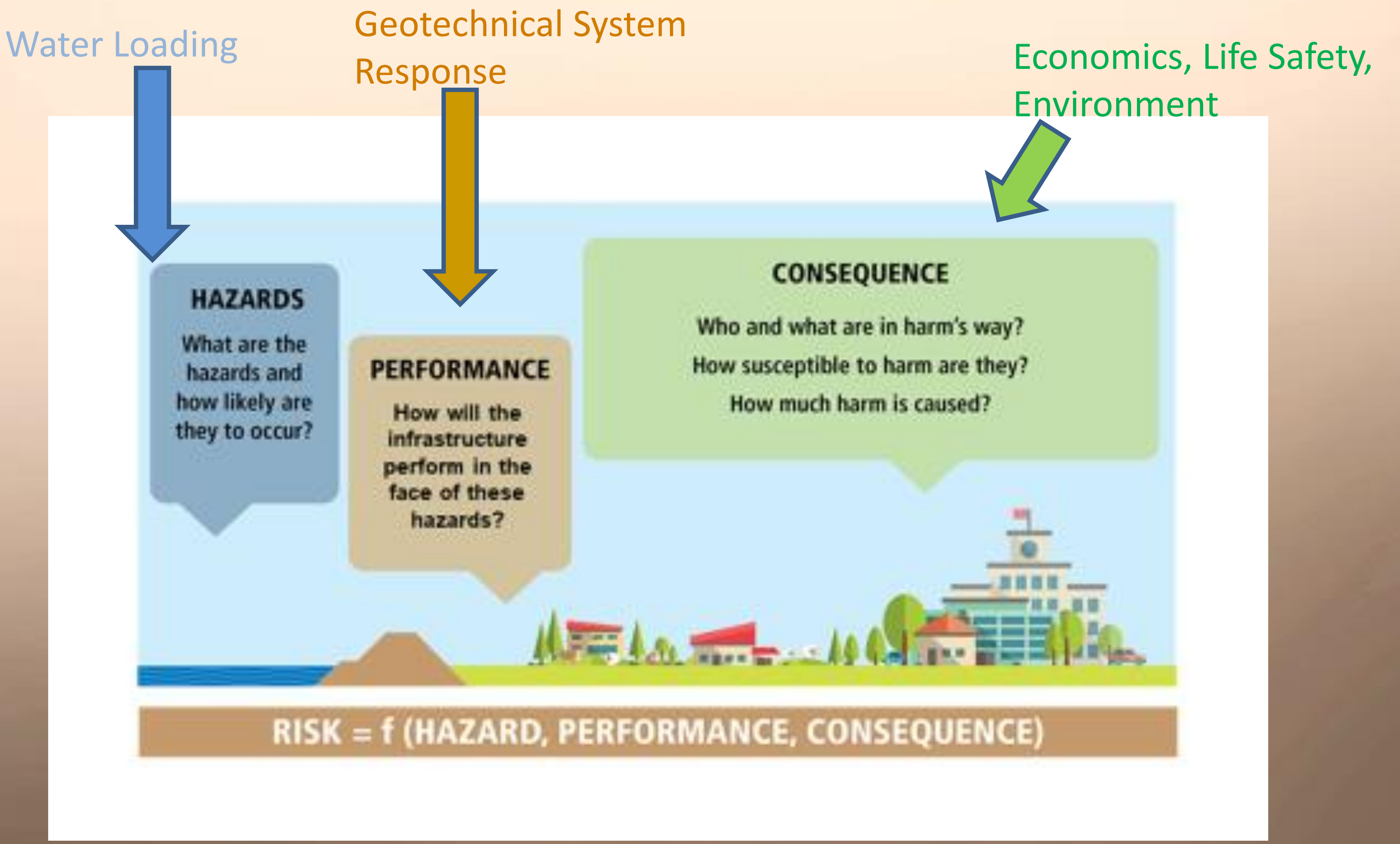
“Current” Guidance

- ETL 1110-2-588 Geotechnical System Response Curves for Risk Assessments, 15 October 2020
- ETL 1110-2-561 Reliability Analysis And Risk Assessment For Seepage And Slope Stability Failure Modes For Embankment Dams (expired 30 June 2010)
- New EM 1110-2-1913, Design and Construction of Levees, may have some R&U guidance when it is approved.

Basin Impact Cases

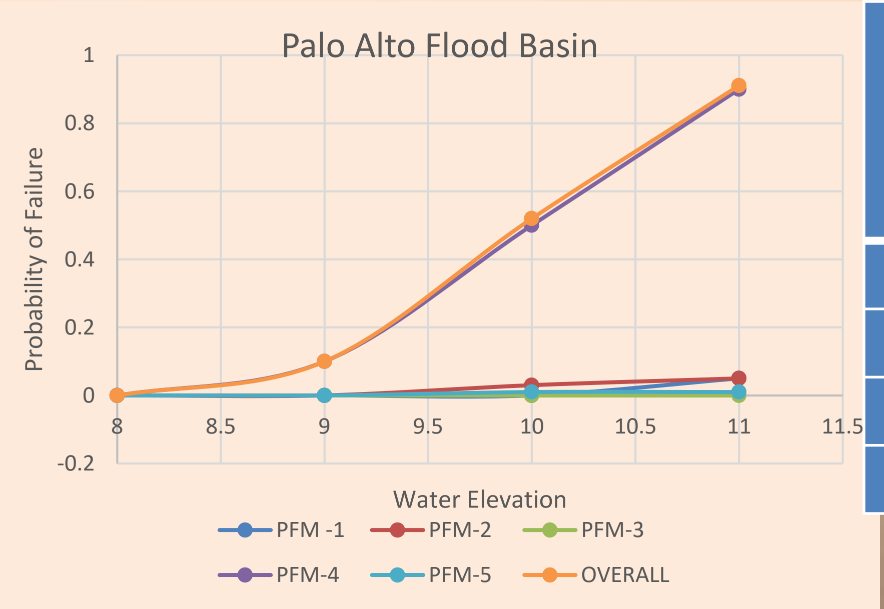
Risk Equation

- Risk = Hazard x Performance X Consequences



Geotechnical System Response Curve

From ETL 1110-2-588:
"The system response curve represents the conditional **probability of failure** leading to inundation and associated economic/life safety consequences"



Peak Water Elevation (ft.)	Pf PFM - 1	Pf PFM-2	Pf PFM-3	Pf PFM-4	Pf PFM-5	OVERALL
8	0	0	0	0	0	0.00
9	0	0	0	0.1	0	0.10
10	0	0.03	0	0.5	0.01	0.52
11	0.05	0.05	0	0.9	0.01	0.91

Geotechnical Engineering and the B/C Ratio

- Geotechnical engineering often impacts both benefits and costs.
- Performance functions developed by geotechnical engineers impact HEC-FDA calculations of damages and benefits.
- Geotechnical design requirements impact costs associated with construction of new or improvements to levees, dams, spillways, weirs, etc.

Poor performance = lots of potential benefits, but requires expensive design to remediate.

Needed for without project and with project

Geotechnical Uncertainty is sometimes a major contributor to cost and schedule risk

Level of Effort for SMART Planning

- All the engineering that matters and none that doesn't matter.
- Get the future without project models up and running as soon as possible.
- Perform sensitivity analysis
- Identify inputs that will impact results
- Fair comparison of alternatives vs level of accuracy for budgeting?
- Increased accuracy of new project may be needed for focused array and TSP and/or LPP
- "Regardless of which method is chosen to develop performance functions, a clear rationale shall be provided in study documentation to support the method used and describe the limitations of the use of the performance function."

Part 2 Review: The Big Picture

- USACE policy and guidance
- Overtopping vs breach prior to overtopping
- Risk equation
- Performance function definition
- Geotechnical impacts to B/C ratio
- Level of effort for SMART Planning

Part 2 Outline: Developing Performance Functions

- Poor performance vs. levee breach
- Geotechnical failure modes
- Performance function development approaches
- Applying approaches to failure modes
- Combining individual failure mode curves

Part 3 Outline:
Developing Performance Functions

- Poor performance vs. levee failure
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Typical Geotechnical Failure Modes

- Embankment stability
- Underseepage
- Through seepage
- Erosion
- Contributing factors
  - Encroachments
  - Utilities
  - Animal Burrows
  - Vegetation

Failure Mode Identification

Slope Instability of the Landside Levee Slope PFM-1: In this failure mode, water seeps through the levee, causing a reduction of effective stress of the soils. The landside of the levee fails and causes loss of levee crest elevation, water overtopping and levee breach

Under seepage Causes a Landside Boil, PFM-2: In this failure mode, a sand layer is located directly beneath the bay mud, transmitting high pore pressures from the waterside of the levee to the landside of the levee and have a vertical gradient across the blanket that causes a sand boil at the toe of the levee

Wind waves erode the levee, PFM-3: In PFM-3 wind-induced waves cause erosion of the levee from the bay side toward the interior of the flood basin.

Levee Overtopping, PFM-4: In this failure mode water overtops the levee, causing erosion on the landside of the levee, that eventually leads to breach.

Poor Performance vs. Failure

- Past confusion of poor performance vs. failure
  - From ETL 1110-2-588:

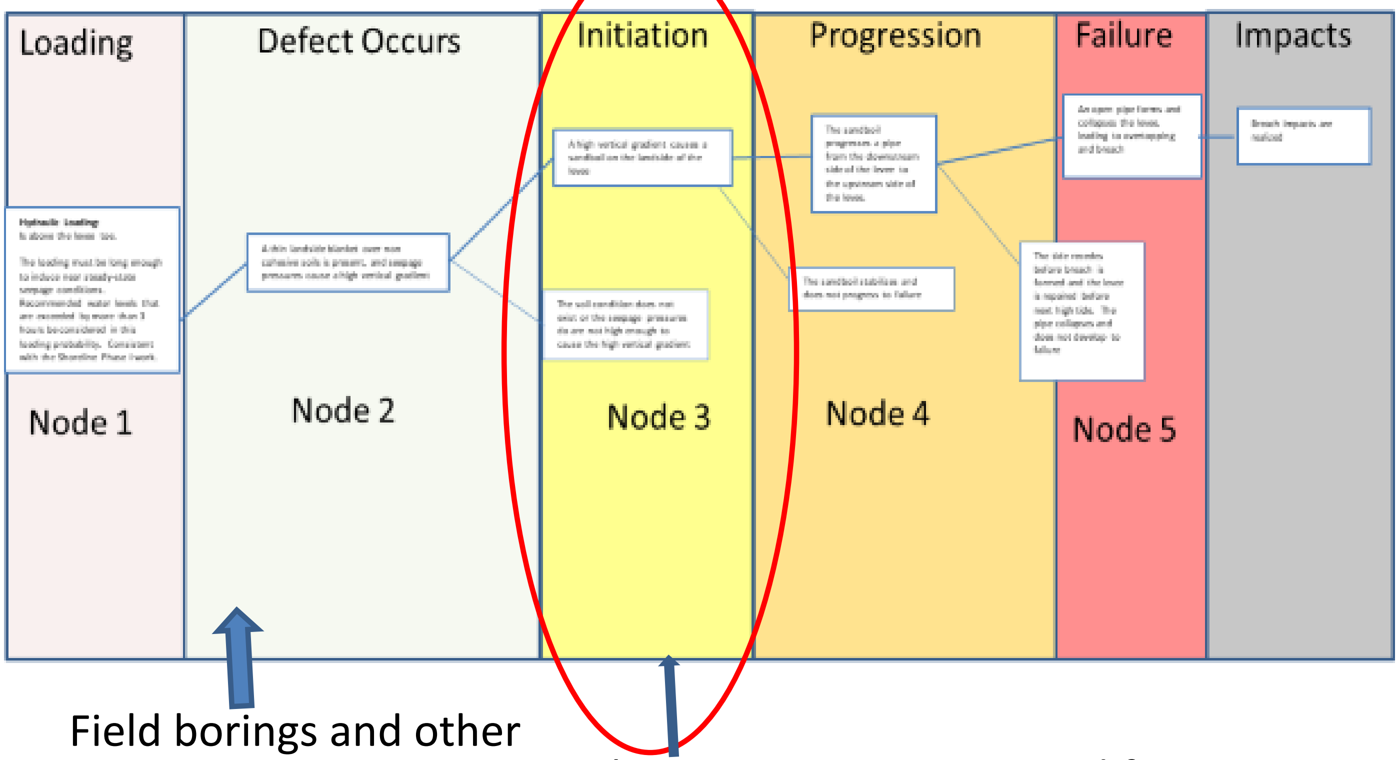
    The system response curve represents the conditional probability of failure leading to inundation and associated economic/life safety consequences
- Poor performance examples:
  - Landside slump with factor of safety (FOS) < 1 that does not breach the levee
  - Heave at the levee toe with boils with FOS < 1 but does not progress to failure.
- Failure Examples
  - Water enters the economic impact area from the channel
  - Carpets get wet…

Failure Event Progression

Figure 2.
Event Tree for: PFM 2

PFM 2 Description: Water loading causes under seepage and uplift gradients on the landside of the levee that lead to soil piping, increasing seepage, erosion and levee collapse, allowing the water to overtop the levee and eventually leading to breach.

Hydraulic Loading: This failure mode may occur at any water level, but is more likely as the water level increases on the levee height.



Field borings and other investigations may be needed

There is sometimes a need for heavy geotechnical analysis here

Poor Performance vs. Levee Failure

Poor Performance vs. Levee Failure

Poor Performance vs. Levee Failure

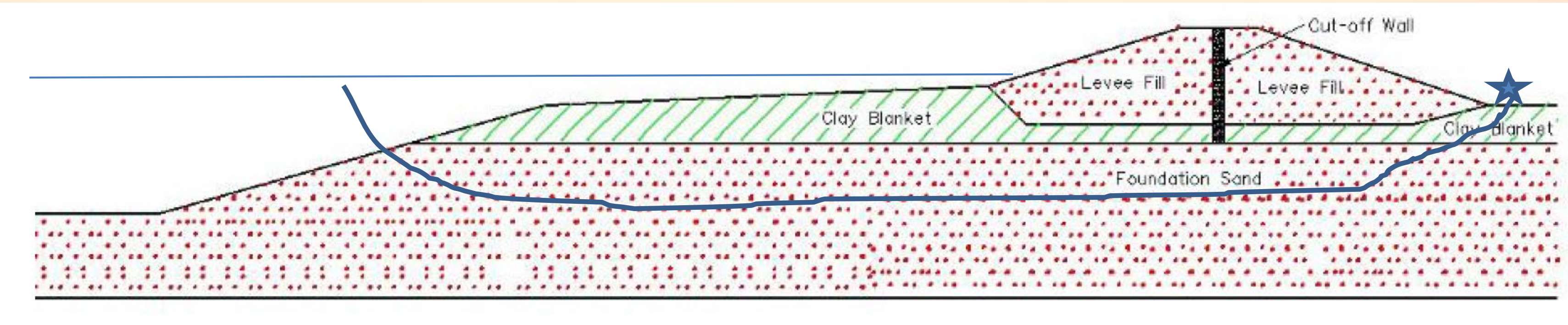
Unanticipated Failure of Sutter Bypass Levee in the 1997 Floods.

Poor Performance vs. Levee Failure

Curve Development Approaches

- From ETL 1110-2-588:
  - *There are several methods that may be used to evaluate the system response component of risk, including reliability analysis (probabilistic limit state), empirical, frequency based and expert elicitation methods, as contained in Reference 3.c*
- *Probabilistic Limit State*
  - Need a lot of data
  - Takes time and funding
  - Probability of poor performance (may be useful for comparative purposes)
- Empirical
  - Failure probabilities based on correlations with observed performance of similar projects (levee screening tool)
- Frequency based
  - Use event trees
  - Informed by analysis at key event tree nodes
  - Use judgment for other event tree nodes
    - Expert panel
    - Risk cadre
    - Local cadre with RMC-trained facilitator
- Expert elicitation
  - Uses available data
  - Quicker and less expensive
  - Not repeatable
  - Probability of Breach prior to overtopping

Statistical Computation



Underseepage Analysis
Levee on Infinite length foundation

T. F. Wolff
September 1994

H = 20
x2 = 110

	kf/kb	z	d	x3	s	ho	i	Variance component	% of variance
mean	1000	8	80	800.00	910.00	9.357	1.170		
	600	8	80	619.68	729.68	9.185	1.148		
	1400	8	80	946.57	1056.57	9.451	1.181	0.000276532	0.30
	1000	6	80	692.82	802.82	9.265	1.544		
	1000	10	80	894.43	1004.43	9.421	0.942	0.090606378	99.69
	1000	8	75	774.60	884.60	9.337	1.167		
	1000	8	85	824.62	934.62	9.375	1.172	5.55296E-06	0.01
							Total	0.090888464	100.00

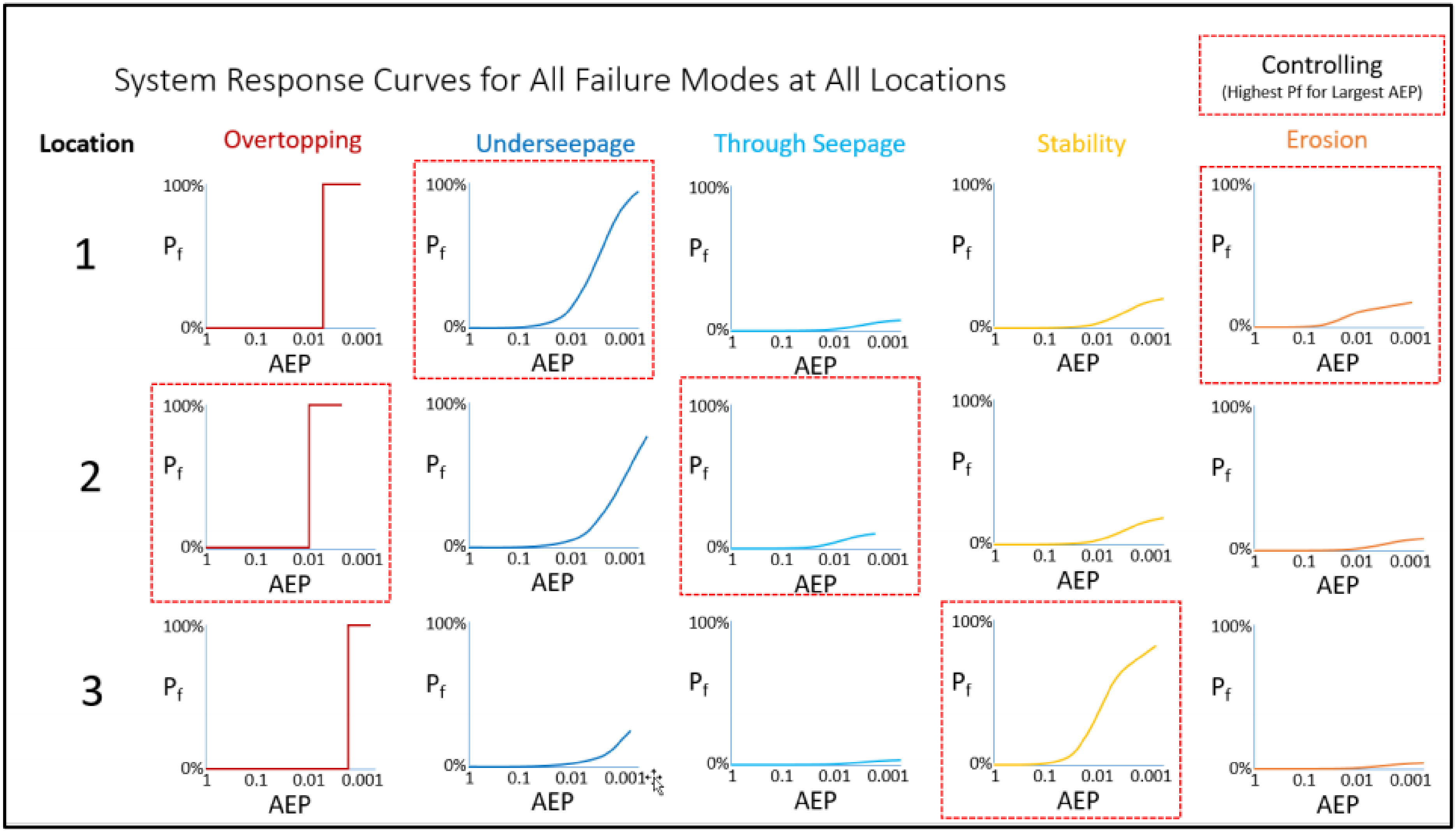
E[i] = 1.170
Var[i] = 0.090888
sigma[i] = 0.301477
V(i) = 25.78%

E[ln i] = 0.12449
sigma[ln i] = 0.253629

i crit = 0.85
ln(i crit) = -0.16252

Pr(f) = 0.871101

Statistical Computation



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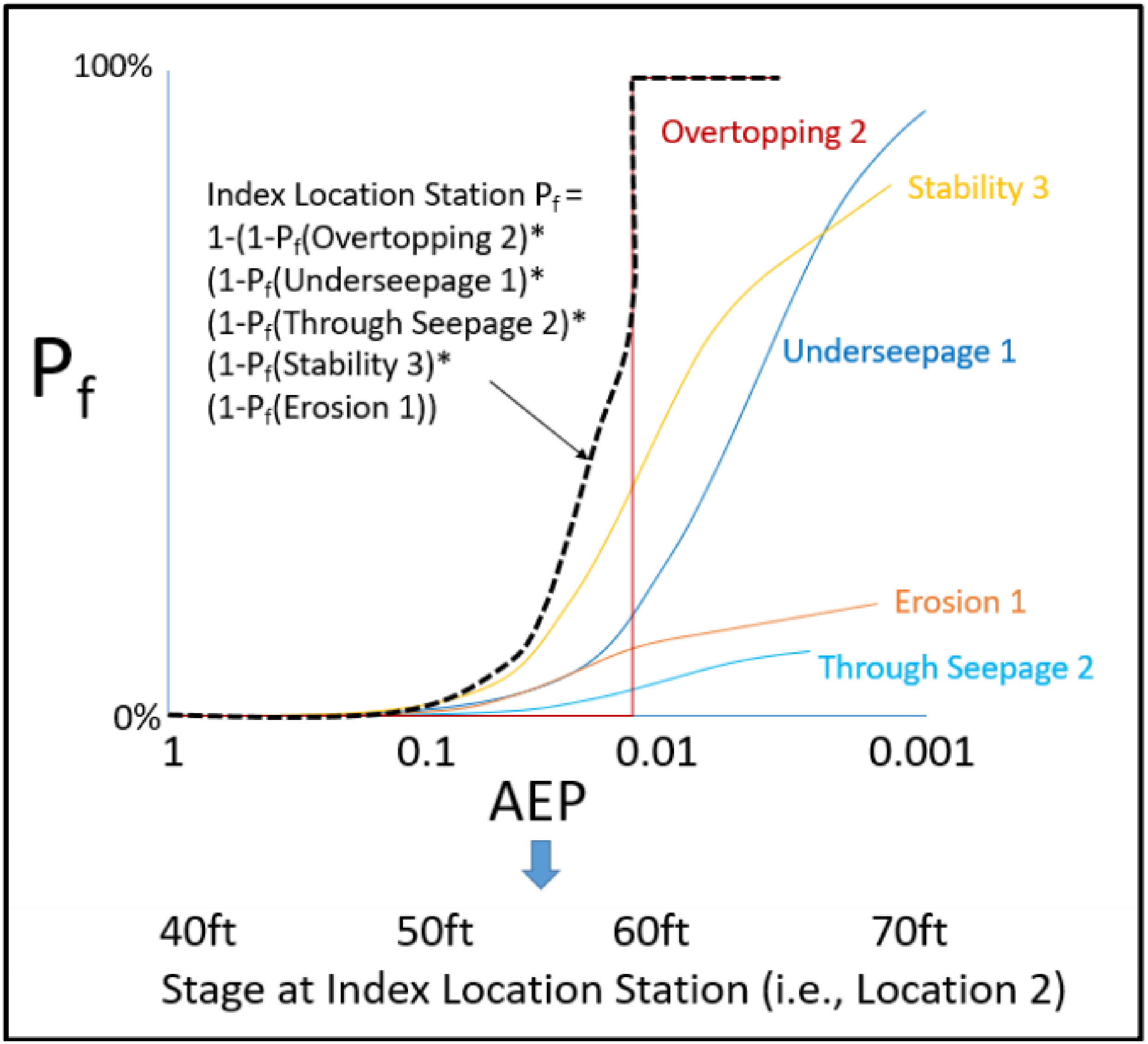

Part 3 Review
Developing Performance Functions

- Poor performance vs. levee failure
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Part 3 Outline
Trouble-Shooting HEC-FDA Results

- Annual Exceedance Probability
- Determining if results are reasonable
- Sources of unreasonable results
- Case Study: Natomas

Part 4 Outline
Trouble-Shooting HEC-FDA Results

- Annual Exceedance Probability
- Determining if results are reasonable
- Sources of unreasonable results
- Case Study: Southbay Shoreline I

Annual Exceedance Probability (AEP)

- The probability in a given year that **flood waters will enter the economic impact area**.
- AEP = 1/recurrence interval
- In the vernacular, recurrence interval is the same as a nominal x-year event.
- An impact area with an AEP of 0.05 (or 1/20) has a recurrence interval of 20 years and is said to have 20-year protection.

Determining if Results are Reasonable

Example 1: The NED plan and LPP are aligned and are believed to provide about 100-year protection. Which of the following ranges might you use to judge the reasonableness of the **with-project** HEC-FDA model results?

- AEP between 1/1 and 1/1000
- AEP between 1/90 and 1/110
- AEP between 1/50 and 1/200
- B/C ratio greater than 3

Determining if Results are Reasonable

Example 2: An impact area has not flooded during the 150 years records have been kept. However, extensive flood fighting saved the levee during three different flood events and PL84-99 repairs were made after each of the flood events. Which of the following statements about the future without project condition are likely to be true?

- The impact area has at least 150-year protection,
  AEP is less than 1/150.
- The AEP is likely between 1/10 and 1/100
- Depending upon the sensitivity of the model to the performance functions, additional research may be warranted to refine the future without project performance curves.

Types of Unexpected AEP Results

- Without project AEP does not match past performance.
- With project AEP doesn't match expected performance.
- Does unexpected mean unreasonable?
- What are possible sources of unexpected HEC-FDA results.

Sources of Unexpected AEP Results

- Levee crest elevation is inaccurate (datum or new construction).
- Recent upstream levee improvements reduce upstream levee failures. Past performance is no longer a predictor of future performance.
- Stage-frequency is not sufficiently accurate.
- Performance function is not sufficiently accurate.
- Interaction between multiple index points in one impact area.

Case Study

- Shoreline I Levee Project
- Immature Guidance at the Time
- Surprising results
- Trouble-shooting
- Current status

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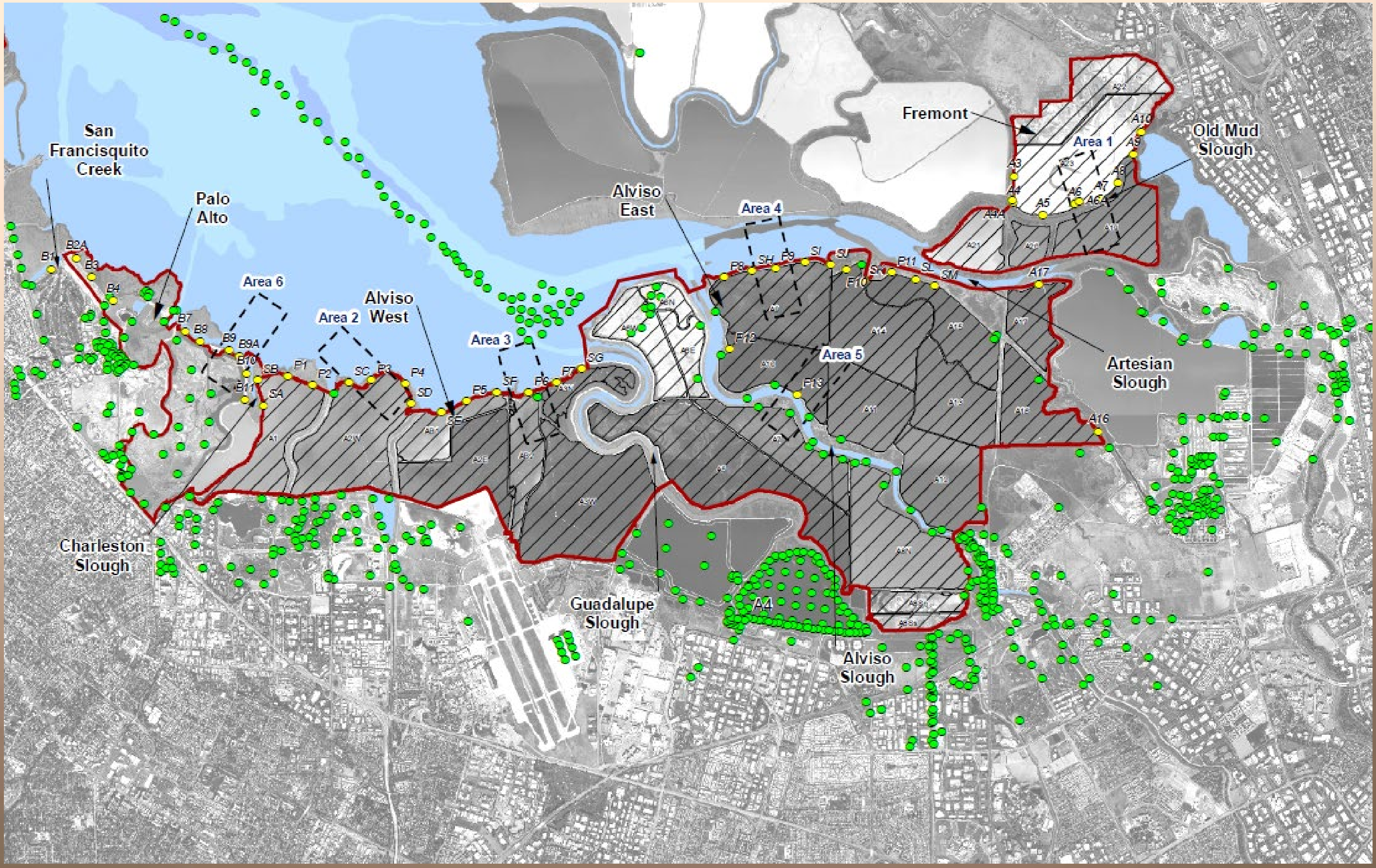
South San Francisco Bay Shoreline. Some Lessons Learned



Shoreline Early Work

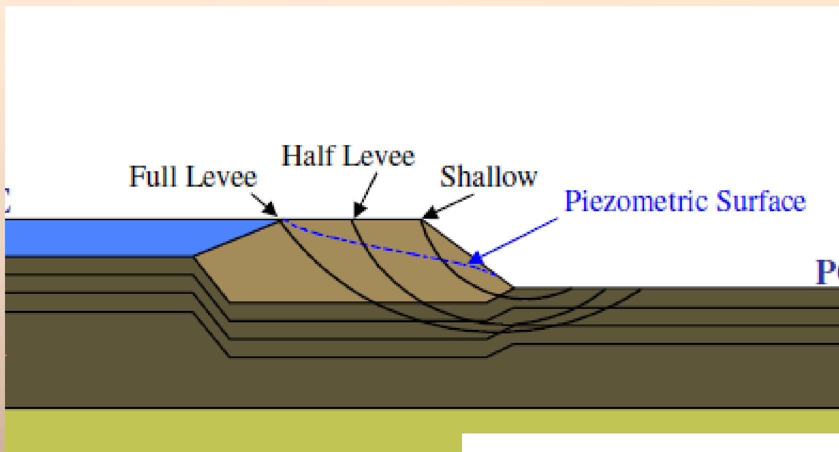
- Very high frequency of flooding didn’t match reality
  - Uncertainty of datums
  - Model coding (monte carlo, vs joint probability calculations)
  - Length considerations vs Index Points
  - Difficulty modeling of P_u vs P_f

Many engineers tend to make conservative decisions.

What is wrong with this table?

Slip Surface	Probability of Unsatisfactory Performance, *Pu* : FS<1.1					
	Area 1	Area 2	Area 3	Area 4	Area 5	Area 6
Shallow	92%	98%	77%	83%	99%	1%
Half Levee	62%	79%	67%	27%	99%	0.5%
Full Levee	23%	46%	58%	5%	98%	0.1%

Everything should be done to FS = 1.0 (remember poor performance vs failure)



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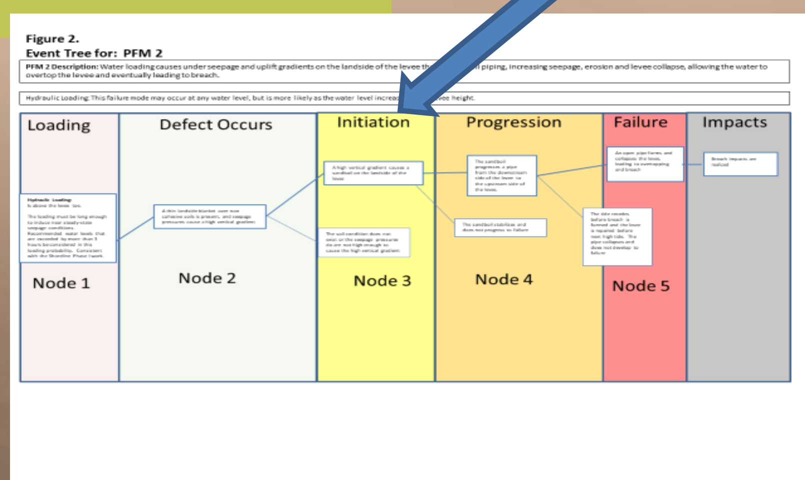
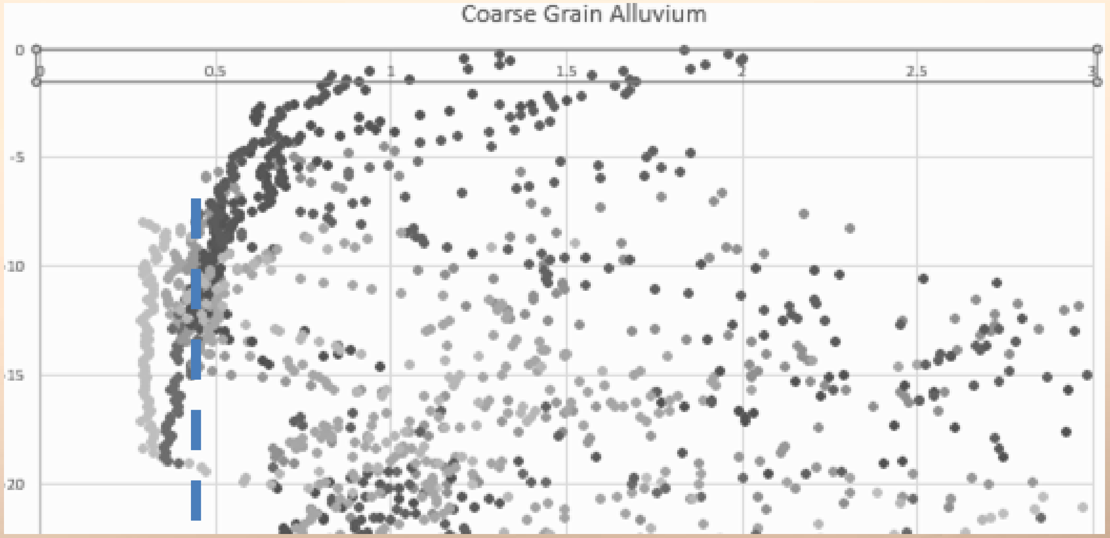
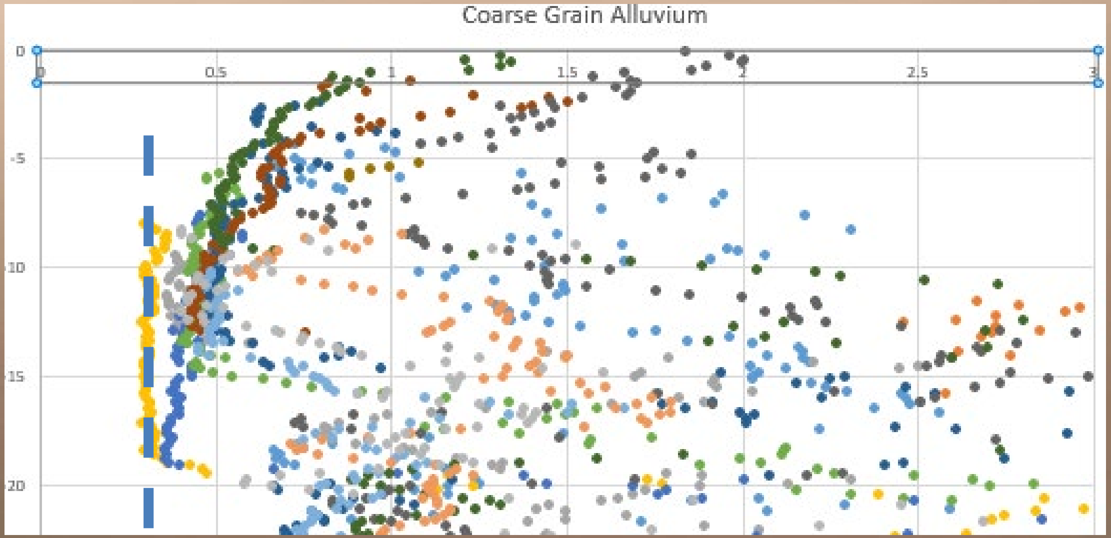


Aleatory Variability and Epistemic Uncertainty in Geotechnical Engineering

- Aleatory Variability – randomness of process
- Epistemic Uncertainty - The epistemic uncertainty is characterized by alternative models.

Aleatory Variability or Epistemic Uncertainty





Part 4 Outline
Trouble-Shooting HEC-FDA Results

- Annual Exceedance Probability
- Determining if results are reasonable
- Sources of unreasonable results
- Case Study: Shoreline

Any Questions?

Performance Functions

Schedule Issues

- Without project model schedule:
  - SMART Planning is iterative
  - Time for first iteration is about 3 months
- Perfect fragility curves:
  - don't represent actual residual risk
  - won't support a risk-based design
  - useful for sensitivity study or to support no TSP