Best Practices in Dam and Levee Safety Risk Analysis

VIII-3 Construction Risks

10 June 2015

U.S. DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

RECLAMATION
Managing Water in the West

US Army Corps of Engineers
BUILDING STRONG®

Construction Risks

- Used primarily for construction of risk reduction measures
- Also used for non-Dam Safety construction activities
- Substantial interaction with decision-makers

Why Evaluation Construction Risks

- Decisions may be made to temporarily expose the public to greater risk to reduce long-term risk
- May cost more to reduce construction risks
- Important to highlight the trade-offs between cost effectiveness and risks
- Need to integrate with alternatives development and update in final designs (based on detailed construction schedule)
- Can't wait till end of process to consider construction risks – they may influence selection of preferred alternative and construction costs

Conditions that lead to Increased Risks

- Excavations lowering the crest of the dam
- Excavations at the toe of a dam
- Excavations that remove portions of the downstream foundation
- Full or Partial closure of appurtenant structures (primarily spillways) reducing release capacity

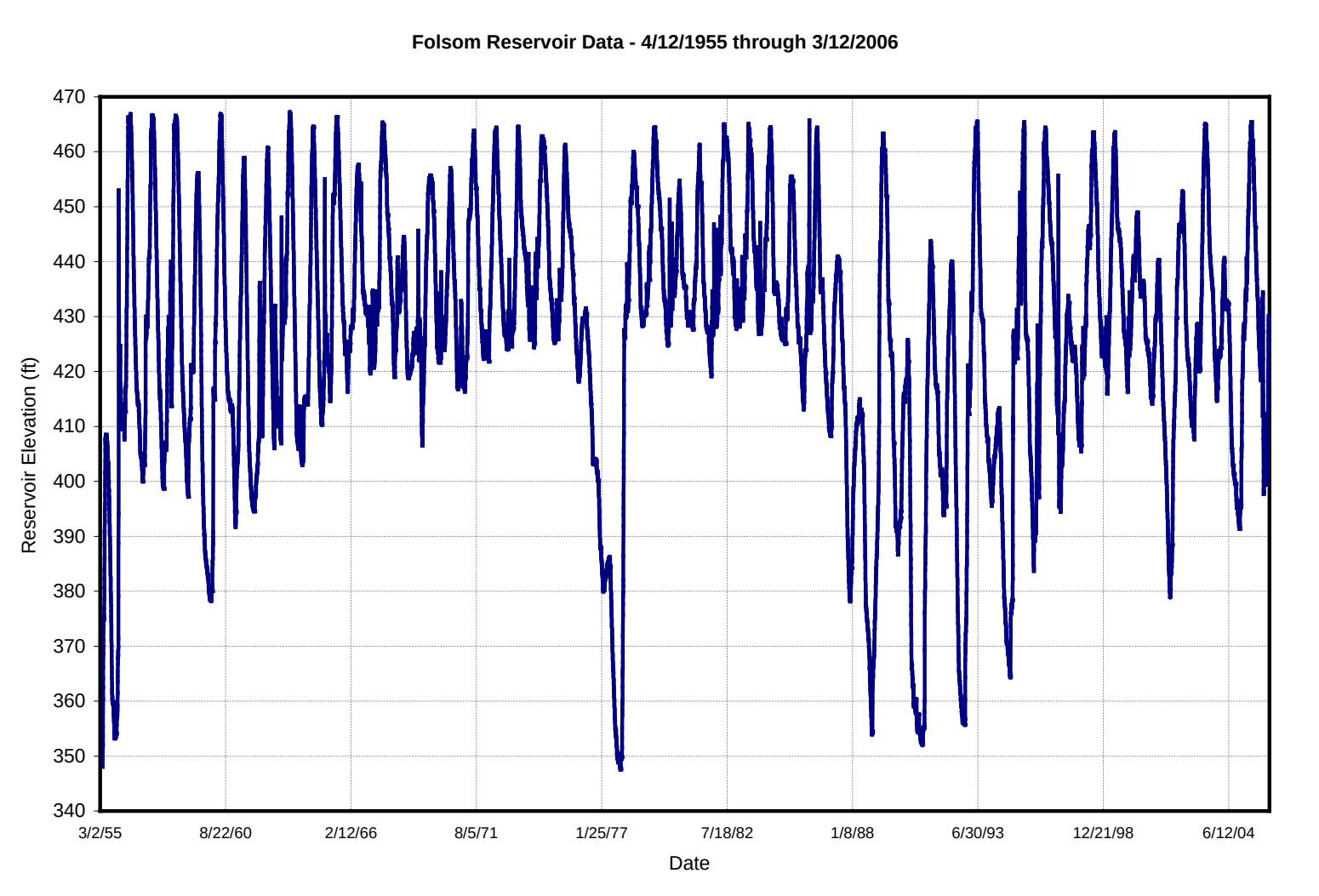
Conditions that lead to Increased Risks

- Cofferdam design
  - Need to include consequences of failure in the selection of design flood
  - Will failure of cofferdam lead to failure of main dam or just flooding of work areas?
  - What are tradeoffs between costs and reduction in risk?
  - Involve decision makers

Important Considerations

- Duration of Construction
- Magnitude of Potential Problems
- Increases the likelihood of other failure modes
- Ability to mitigate problems if they occur
- Redundancy
- Contract Language
- Portrayal of Risks to Different Audiences
- Dam safety risks need to be managed thru specs
- For risks that are construction risks only and not dam safety (only affect contractor and his operations), contractor may be allowed to choose level of protection

Example


Folsom Reservoir Data - 4/12/1955 through 3/12/2006
Reservoir Elevation (ft)
470
460
450
440
430
420
410
400
390
380
370
360
350
340
3/2/55
8/22/60
2/12/66
8/5/71
1/25/77
7/18/82
1/8/88
6/30/93
12/21/98
6/12/04
Date

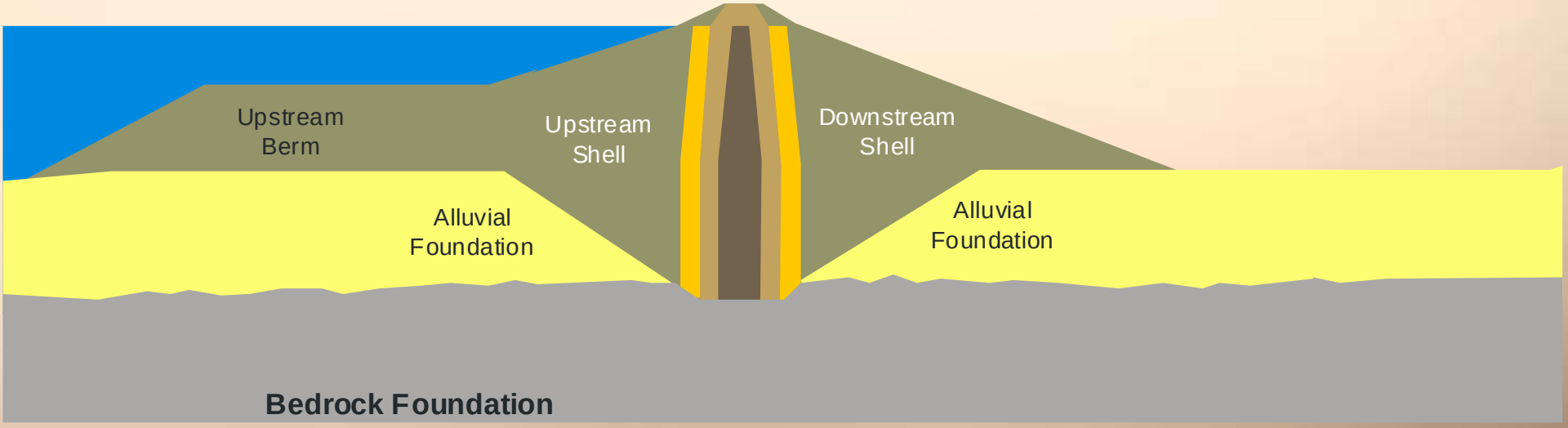
Example Foundation Liquefaction Remediation

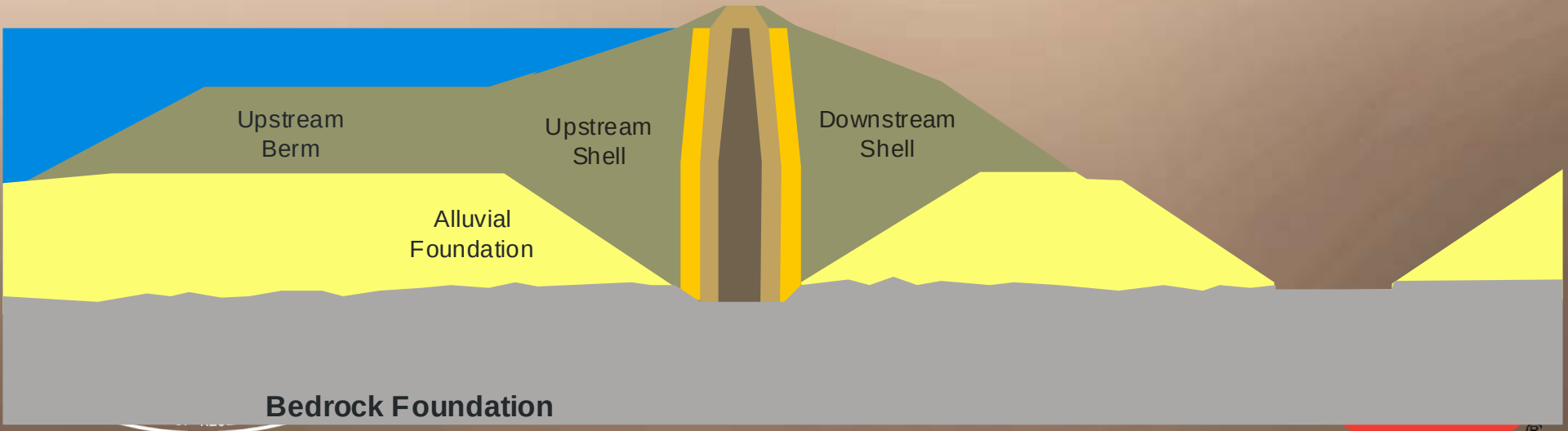
- Considerations:
- Field Construction Cost
- Ability to Meet Long Term Risk Reduction Guidelines
- Risk During Construction
- Cost Uncertainty
- Schedule Delay Potential
- Technical Concerns or Lack of Concern

Alternatives Considered

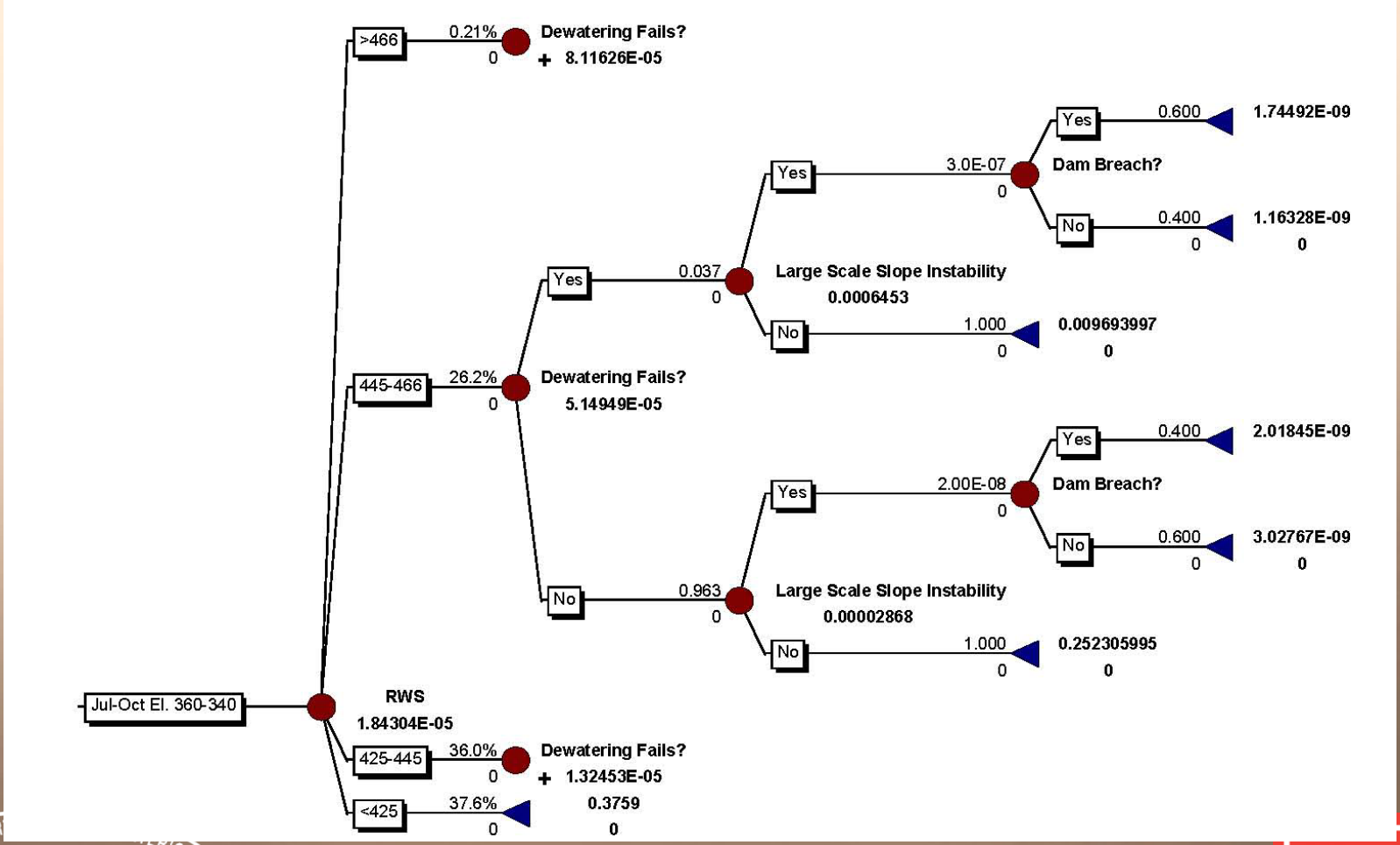
1. Open Excavation (4 variants)
2. Double Wall Excavation (3 variants)
3. Cellular Excavation (2 variants)
4. Lattice Cells (2 variants)
5. Drilled Shafts (2 variants)
6. Drilled Hexagonal Cells (2 variants)
7. No Action

Alternative 1 – Excavate Foundation and Replace Material





Risks – Open Excavation – Static Loading



Risks – Open Excavation

Reservoir Water Surface Elevation (ft)	Probability of Failure	
	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}

Risks – Open Excavation

Reservoir Level (ft)	Exceedance Probability		
	March-June	July-October	November-February
465+	0.012	0.0021	0.0002
445	0.38	0.26	0.32
425	0.80	0.62	0.39

Risks – Open Excavation

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

Risks – Open Excavation

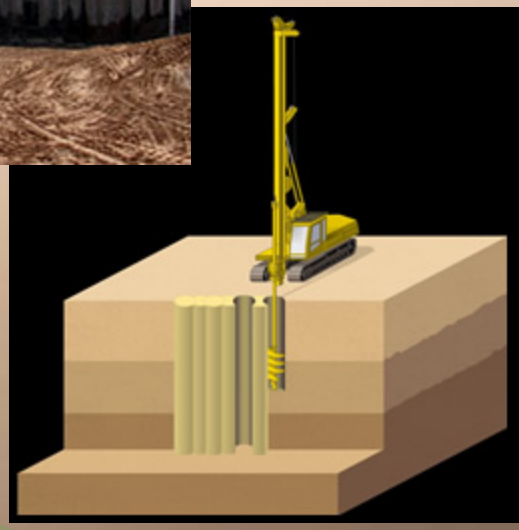
Scenario	Duration (months)	Annual Failure Probability	Annual Loss of Life
One shift beginning July1	4.8	8.06×10^{-6}	7.26×10^{-3}
Two shifts beginning July 1	2.8	4.71×10^{-6}	4.25×10^{-3}
One shift beginning November 1	5.8	1.36×10^{-5}	1.23×10^{-2}
Two shifts beginning November 1	3.4	5.64×10^{-6}	5.07×10^{-3}

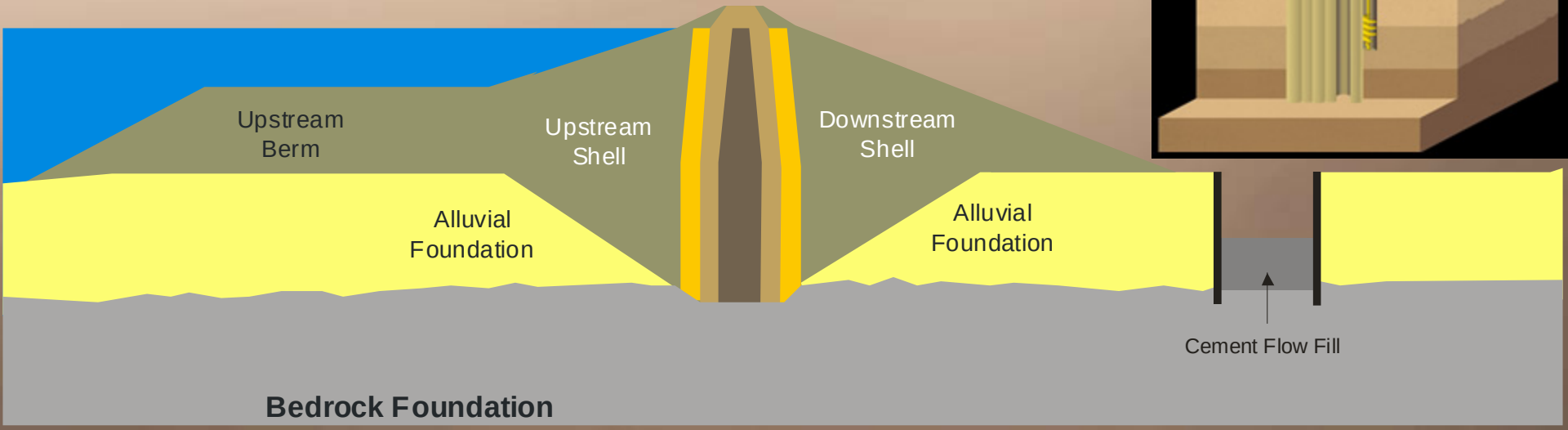
Risk-Duration

- Defined as the sum of the product of risk and duration (in years) for each increment of the excavation
- Compared to baseline over length of construction
- Ratio gives increase in risk

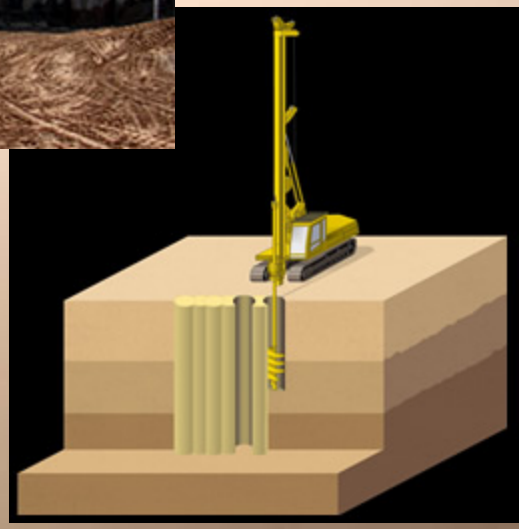
Alternative 2 – Dual Wall Braced Excavation

- Pros:
  - Easy to verify risk reduction
- Cons:
  - Dewatering might prove difficult
  - Expensive ($65-70M)

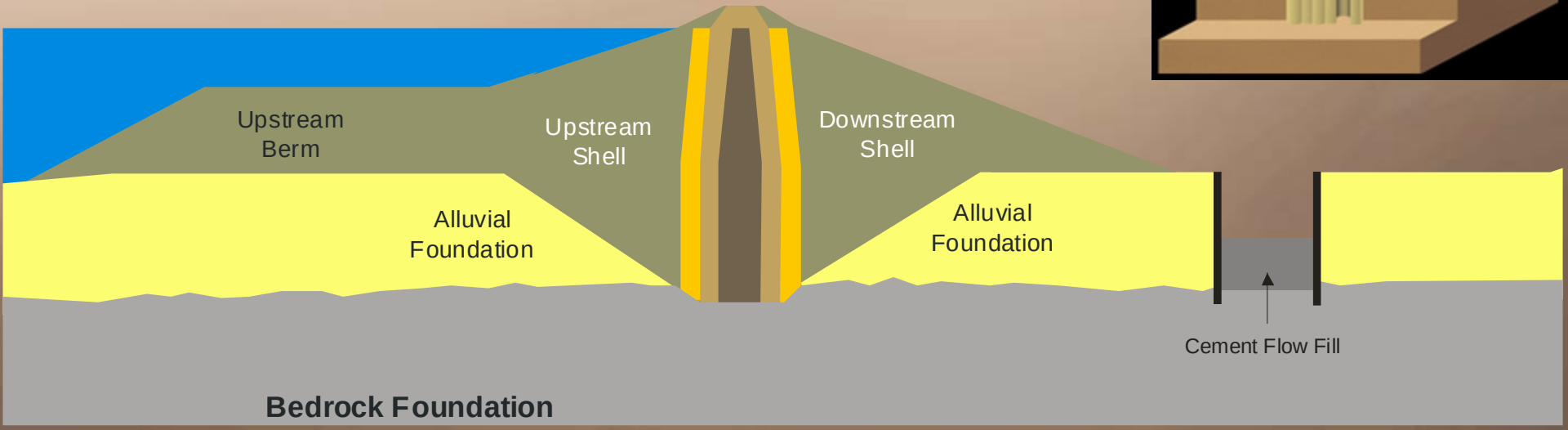




Alternative 3 – Cellular Excavation

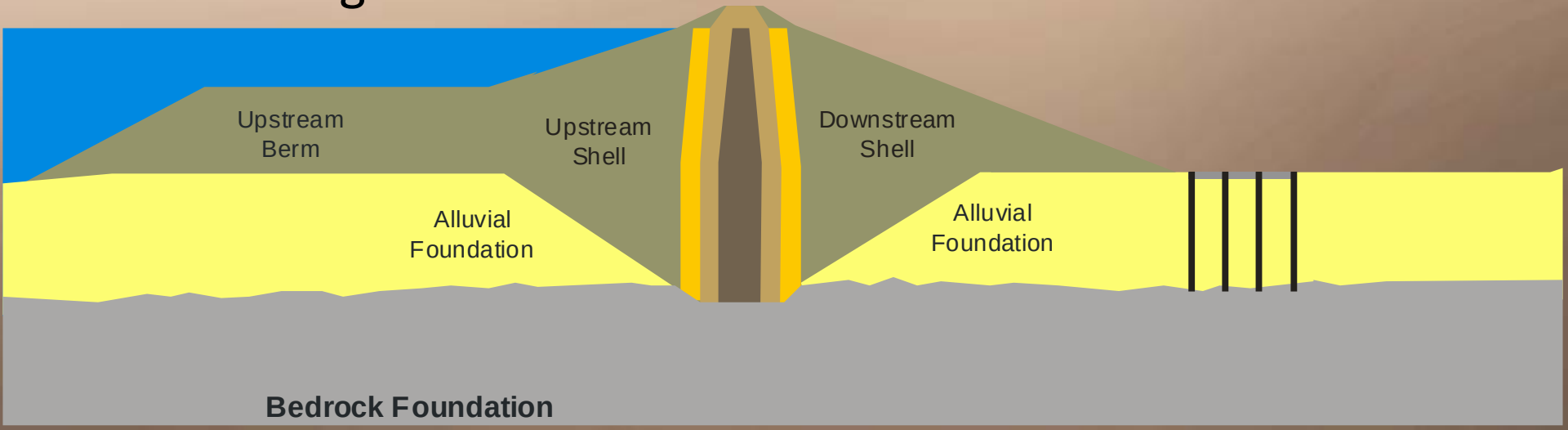


- Pros:
  - Easy to verify risk reduction
  - No dewatering necessary
- Cons:
  - Hydrostatic load critical to stability
  - Expensive ($70M)



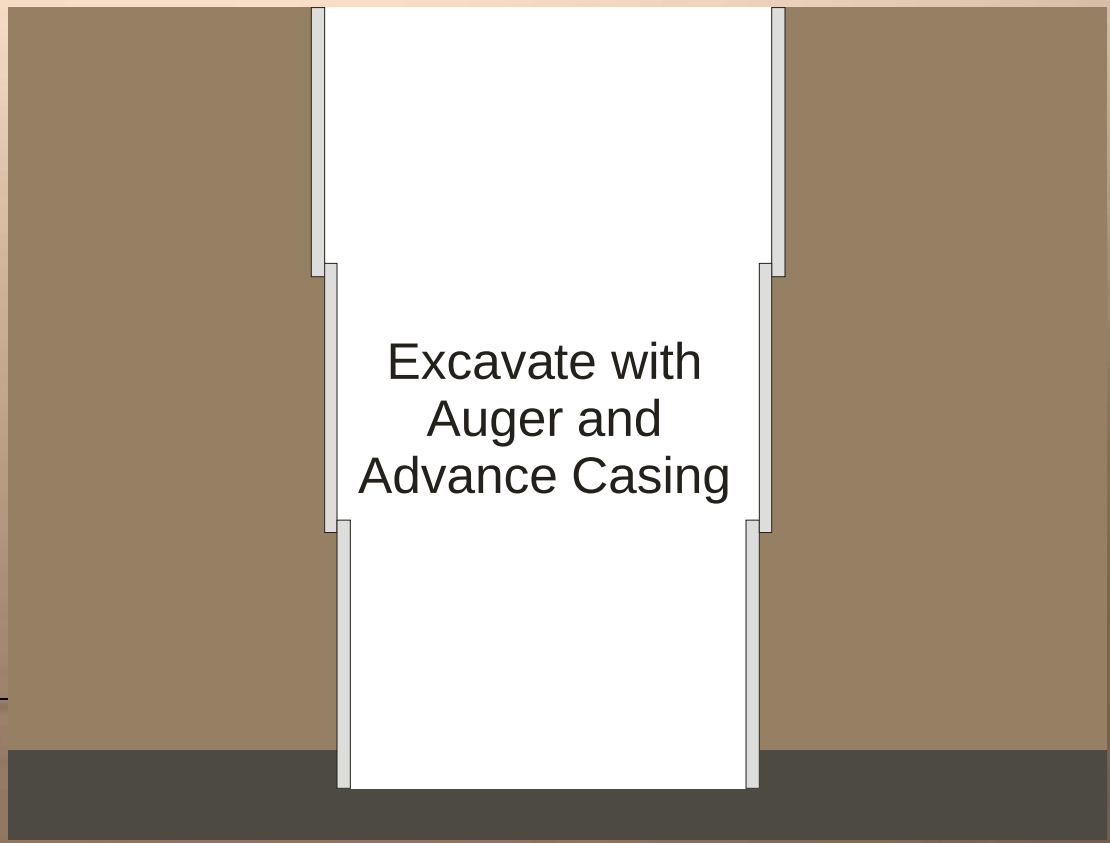
Alternative 4 – Lattice Structure

- Pros:
  - Little to no construction risk
  - Easy to construct
- Cons:
  - Expensive ($58-61M)
  - Would likely not provide enough strength to reduce risk



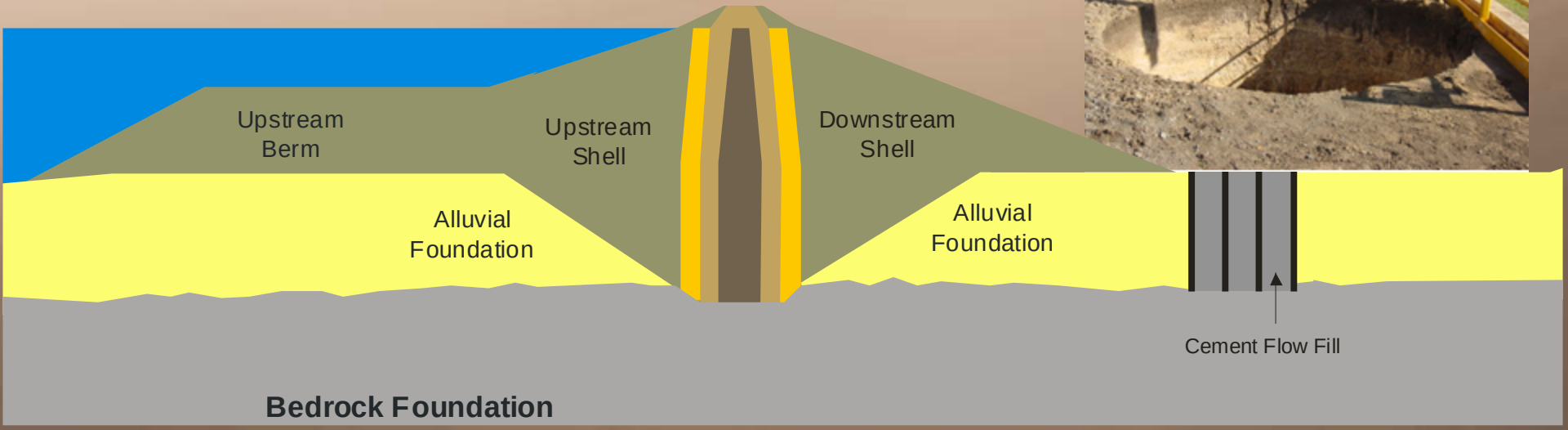
Alternative 5 – Drilled Shafts

- Pros:
  - Very little construction risk
  - Easy to verify risk reduction
  - No dewatering necessary
- Cons:
  - Very expensive ($104M)
  - Somewhat difficult construction



Alternative 6 – Drilled Hexagonal Cells

- Pros:
  - Construction itself fairly easy
  - Little to no construction risks
  - Not as easy to verify risk reduction
  - No dewatering necessary
  - Several contractors can drill 15’ cells
- Cons:
  - Expensive ($66-77M)



Foundation Alternatives

	Duration	Field Cost ($ Million)	Additional Risk During Construction
1 – Open Excavation	8 Months	$36-43	5.0 – 16.0
2 – Double Wall	12-17 Months	$65-70	3.0 – 5.0
3 – Cellular	23-42 Months	$70	1.0 – 4.0
4 – Lattice Structure	N/A	$58-61	1.0
5 – Drilled Shafts	N/A	$104	1.0
6 – Hexagonal Cells	24-30 Months	$66-77	1.0 - 4.0
7 – No Construction	0 Months*	$0	1.0

Foundation Alternatives

	Technical Concerns	Long Term Risk Reduction	Risk of Construction Delays
1 – Open Excavation	Significant	Yes	High
2 – Double Wall	Some to Significant	Yes	Moderate
3 – Cellular	Some	Yes	Low
4 – Lattice Structure	Very Significant	No	None
5 – Drilled Shafts	Significant	No	None
6 – Hexagonal Cells	Some	Yes	Very Low
7 – No Construction	None	No	None

Hydrologic Construction Risks

- Reducing spillway capacity or lowering dam crest may increase risk of dam overtopping during large floods
- Construction risks can be minimized by:
  - Schedule or stage work to reduce risk (minimize exposure during flood season)
  - Temporarily restrict reservoir during critical phases of work
- Costs of alternative construction schedules need to be identified and portrayed

Hydrologic Construction Risks

- Seasonal floods and starting reservoir water surface elevations may need to be considered if construction activities are limited to certain months or periods
- May need to consider more remote floods if dam overtopping is an issue
- For construction only risks – need to portray potential for more frequent floods