Best Practices in Dam and Levee Safety Risk Analysis

VIII-3 Construction Risks

10 June 2015
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)

Date

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
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

<table>
<thead>
<tr>
<th>Reservoir Water Surface Elevation (ft)</th>
<th>Probability of Failure</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Dewatering System Fails</td>
<td>Dewatering System Works</td>
<td></td>
</tr>
<tr>
<td>2470</td>
<td>4.0x10^{-2}</td>
<td>2.4x10^{-6}</td>
<td></td>
</tr>
<tr>
<td>2465</td>
<td>2.0x10^{-3}</td>
<td>2.4x10^{-6}</td>
<td></td>
</tr>
<tr>
<td>2445</td>
<td>4.0x10^{-4}</td>
<td>2.4x10^{-6}</td>
<td></td>
</tr>
<tr>
<td>2425</td>
<td>2.0x10^{-5}</td>
<td>2.4x10^{-6}</td>
<td></td>
</tr>
</tbody>
</table>
## Risks – Open Excavation

<table>
<thead>
<tr>
<th>Reservoir Level (ft)</th>
<th>March-June</th>
<th>July-October</th>
<th>November-February</th>
</tr>
</thead>
<tbody>
<tr>
<td>465+</td>
<td>0.012</td>
<td>0.0021</td>
<td>0.0002</td>
</tr>
<tr>
<td>445</td>
<td>0.38</td>
<td>0.26</td>
<td>0.32</td>
</tr>
<tr>
<td>425</td>
<td>0.80</td>
<td>0.62</td>
<td>0.39</td>
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</tbody>
</table>
### Risks – Open Excavation

<table>
<thead>
<tr>
<th>Season</th>
<th>Annual Failure Probability</th>
<th>Annualized Loss of Life</th>
</tr>
</thead>
<tbody>
<tr>
<td>March-June</td>
<td>4.66x10^{-5}</td>
<td>4.20x10^{-2}</td>
</tr>
<tr>
<td>July-October</td>
<td>2.02x10^{-5}</td>
<td>1.82x10^{-2}</td>
</tr>
<tr>
<td>November-February</td>
<td>1.99x10^{-5}</td>
<td>1.79x10^{-2}</td>
</tr>
</tbody>
</table>
## Risks – Open Excavation

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Duration (months)</th>
<th>Annual Failure Probability</th>
<th>Annual Loss of Life</th>
</tr>
</thead>
<tbody>
<tr>
<td>One shift beginning July 1</td>
<td>4.8</td>
<td>$8.06 \times 10^{-6}$</td>
<td>$7.26 \times 10^{-3}$</td>
</tr>
<tr>
<td>Two shifts beginning July 1</td>
<td>2.8</td>
<td>$4.71 \times 10^{-6}$</td>
<td>$4.25 \times 10^{-3}$</td>
</tr>
<tr>
<td>One shift beginning November 1</td>
<td>5.8</td>
<td>$1.36 \times 10^{-5}$</td>
<td>$1.23 \times 10^{-2}$</td>
</tr>
<tr>
<td>Two shifts beginning November 1</td>
<td>3.4</td>
<td>$5.64 \times 10^{-6}$</td>
<td>$5.07 \times 10^{-3}$</td>
</tr>
</tbody>
</table>
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

Excavate with Auger and Advance Casing
**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

<table>
<thead>
<tr>
<th>1 – Open Excavation</th>
<th>8 Months</th>
<th>$36-43</th>
<th>5.0 – 16.0</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 – Double Wall</td>
<td>12-17 Months</td>
<td>$65-70</td>
<td>3.0 – 5.0</td>
</tr>
<tr>
<td>3 – Cellular</td>
<td>23-42 Months</td>
<td>$70</td>
<td>1.0 – 4.0</td>
</tr>
<tr>
<td>4 – Lattice Structure</td>
<td>N/A</td>
<td>$58-61</td>
<td>1.0</td>
</tr>
<tr>
<td>5 – Drilled Shafts</td>
<td>N/A</td>
<td>$104</td>
<td>1.0</td>
</tr>
<tr>
<td>6 – Hexagonal Cells</td>
<td>24-30 Months</td>
<td>$66-77</td>
<td>1.0 - 4.0</td>
</tr>
<tr>
<td>7 – No Construction</td>
<td>0 Months*</td>
<td>$0</td>
<td>1.0</td>
</tr>
</tbody>
</table>

*0 Months* refers to no construction time required for this alternative.
# Foundation Alternatives

<table>
<thead>
<tr>
<th></th>
<th>Technical Concerns</th>
<th>Long Term Risk Reduction</th>
<th>Risk of Construction Delays</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 – Open Excavation</td>
<td>Significant</td>
<td>Yes</td>
<td>High</td>
</tr>
<tr>
<td>2 – Double Wall</td>
<td>Some to Significant</td>
<td>Yes</td>
<td>Moderate</td>
</tr>
<tr>
<td>3 – Cellular</td>
<td>Some</td>
<td>Yes</td>
<td>Low</td>
</tr>
<tr>
<td>4 – Lattice Structure</td>
<td>Very Significant</td>
<td>No</td>
<td>None</td>
</tr>
<tr>
<td>5 – Drilled Shafts</td>
<td>Significant</td>
<td>No</td>
<td>None</td>
</tr>
<tr>
<td>6 – Hexagonal Cells</td>
<td>Some</td>
<td>Yes</td>
<td>Very Low</td>
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<tr>
<td>7 – No Construction</td>
<td>None</td>
<td>No</td>
<td>None</td>
</tr>
</tbody>
</table>
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.