TRANSITIONING TO RISK-INFORMED DESIGNS FOR DAMS AND LEVEES

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OUTLINE

• USACE
• Background
• Levee Design Manual – 3 Problems
• Example – Moose Creek
• Example – Herbert Hoover Dike
CORPS OF ENGINEERS
“Infrastructure follows Floods, People Follow Infrastructure”

Portfolio Characteristics:
- Majority are Earthen
- Aging (+55 years)
- Relatively untested

715 Dams
+2,500 Levees
Dams
- 715 Dams
- 80% Earthen and 20% Concrete Gravity on Improved Foundations
- PAR of +12.8M
- Property at risk = +1T
- Total length of 267 miles
- Average age = +55
- Pass extreme flows in controlled manner

Levees
- 2,500 levee segments
- 95% Earthen, 5% Concrete Floodwall on unimproved foundations
- PAR of +9.5M
- Property at risk = +$1.3T
- Total length of 14,700 miles
- Average age = +55
- Pass extreme flows in uncontrolled manner
BACKGROUND

How do they know the load limit on bridges, Dad?

They drive bigger and bigger trucks over the bridge until it breaks.

Then they weigh the last truck and rebuild the bridge.

Oh, I should've guessed.

Dear, if you don't know the answer, just tell him!
HISTORY – WATER RETAINING STRUCTURES (DAMS AND LEVEES)

• Engineering organizations, private consultants, and government agencies have been using regulations, manuals, and guidance published by the Corps of Engineers for nearly 75 years.
• The guidance currently published aggregates many of the lessons learned by the profession from their experience observing the performance of dams and levees worldwide.
• The approach taken by our predecessors, to pass that knowledge to future generations, has led to an improvement in the design and construction processes over the course of the last 75 years.
THE UNDERLYING ISSUE

Every Problem is associated with an -ologist

CHANGE MY MIND
FOUNDATIONS, FILTERS, AND INTERNAL EROSION
CONDUITS AND EARTHQUAKES
LEVEE DESIGNS 1927 – 1970’S

• Examinations of levee failures – led directly to levee design standards
• Geomorphology studies
• Much R&D at the Waterways Experiment Station

• Stability
• Underseepage
• Focused on Lower Mississippi
DESIRE TO REVISE LEVEE DESIGN MANUAL

3 Significant Problems Identified
PROBLEM NO. 1

Not every levee conforms to levee geometry in the lower Mississippi
“It’s great if you are from the Lower Mississippi, but there’s nothing about the types of designs we do here in ______________.”
2011 MISSOURI RIVER PERFORMANCE HISTORY
Factors of safety called out
Traditional dimensions discussed but requirements not set
Past performance and engineering judgment are paramount
PROBLEM NO. 2

We don’t have an analytical model for every failure mode
MARCHAND LEVEE FAILURE 1983
FLOW SLIDES IN SAND

1. Resuspension/Transport
2. sediment during T=1, TO T=2
3. Time T=1, retrogression continues
4. Time T=2, Overburden undercut begins, blocks fail and ride out upon fluidized/liquified layer

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INTERNAL EROSION
PROBLEM NO. 3

We don’t have a model that incorporates intervention
Levee did not fail, but internal erosion pipes projecting towards the river found in 2012.

Example Flood Fighting Evaluation

“More than expected and, but for flood fighting, levee would have failed”

Ensley Berm, Memphis 2011
Example Flood Fighting Evaluation

“Flood fighting occurred but levee failed”

L-575 Breach, NW Atchison County Levee District, Hamburg Iowa 2011

Possibly due to defects in riverside cap - fourth pipe formed and breached on June 13, 2011.
THIS IS NOT THE INTERVENTION WE’RE TALKING ABOUT…
GENERAL PROCESS AND EXAMPLES

This bedrock likely formed as the Dalmatian microplate subducted under East Laika during the Upper Pomeranian.

Geology tip: There are so many microplates and ages that no one remembers them all, so in a pinch you can bluff with dog breeds.
GENERAL PROCESS

1. Have a baseline Potential Failure Mode Assessment and risk assessment
2. Design project using traditional factors of safety
3. Calculate the risk for that design
4. Evaluate the tolerability of the design
5. Modify the design
6. Calculate the risk for that design
7. Evaluate the tolerability of the design
MOOSE CREEK DAM
MOOSE CREEK DAM – ALTERNATIVE

Plan F9:
- Centerline Cutoff Wall: Reaches 4, 5, 6, 8, 9
- APF (FWAC): 2.37E-05 / APF (F9): 1.75E-06
- AALL (FWAC): 5.84E-06 / AALL (F9): 1.11E-04
- Less costly than Plan F10: $102.6 million
- Cost to Save a Statistical Life, and Incremental Average Annual Life Loss versus Incremental Cost is lower than F10.
- Reduces risk around 1 order of magnitude below Tolerable Risk Guidelines.
- Addresses Flaw (biggest risk driver). The Cutoff Wall will interrupt and discontinue the flaw.
- More Efficient than F10.
- Minimal environmental impacts.
- Meets Planning Objectives (TRG) with High Level of certainty.
- Less uncertainty with untested embankment performance.
MOOSE CREEK DAM - HEAVE

- Calculations used to prevent heave of coarse grained soil into a pipe at the bottom of the flaw material.
- Conservative, assumes there is no embankment or foundation material downstream of wall to exit.

Results
- Wall 10 feet below flaw had an unacceptable factor of safety below 1.
- 15 foot wall had no factor of safety below 1.
- Reach 3 transition from 21 feet to initial depth of 56 feet has a low factor of safety.
- Control Works shows inaccurate factor of safety due to excavation.
HERBERT HOOVER DIKE
HERBERT HOOVER DIKE – BACKGROUND

- 2001 – 2005
  - Did not meet exit gradient design criteria
  - Designs formulated to meet criteria
  - Cutoff wall through CIZ A – 200’/65 m deep
  - ~$10M/mile = $2.5 Billion

- 2006 – New Guidance
  - Evaluate Risk
  - Formulate 2 alternatives
  - 1 – Just to tolerable levels
  - 2 – Tolerable levels + 1 order of magnitude
HERBERT HOOVER DIKE – ALTERNATIVES

ALARP Design

Minimum Design
### Herbert Hoover Dike – Evaluation

<table>
<thead>
<tr>
<th>Segments Remediated</th>
<th>Solution</th>
<th>Existing Condition</th>
<th>FWAC/IRRM Permanent</th>
<th>Alternative 1 (Societal Life Safety)</th>
<th>Alternative 2 (Societal, Individual and APF)</th>
<th>Alternative 3 (Societal, and APF with significant consequences)</th>
<th>Alternative 4 (Societal, Individual, APF and Essential Guidelines)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No Action</td>
<td>5-2 and 8</td>
<td>4 - 9</td>
<td>4 - 9 (southern)</td>
<td>4 - 9</td>
<td></td>
<td></td>
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</table>

<table>
<thead>
<tr>
<th>Project Performance</th>
<th>Cutoff-Wall</th>
<th>Cutoff-Wall</th>
<th>Cutoff-Wall</th>
<th>Internal Drainage System</th>
</tr>
</thead>
<tbody>
<tr>
<td>Residual Annualized Probability of Failure (APF)</td>
<td>3.78E-03</td>
<td>3.78E-03</td>
<td>3.78E-03</td>
<td>1.10E-04</td>
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<tr>
<td>Residual Annualized Life Loss (ALL)</td>
<td>1.01E-03</td>
<td>1.66E-04</td>
<td>1.02E-04</td>
<td>6.05E-05</td>
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<tr>
<td>Individual Tolerable Risk</td>
<td>0.00238</td>
<td>0.00238</td>
<td>2.38E-03</td>
<td>6.78E-05</td>
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<table>
<thead>
<tr>
<th>Costs</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
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</thead>
<tbody>
<tr>
<td>Total Estimated Construction Cost</td>
<td>$0</td>
<td>$0</td>
<td>$16,200,000</td>
<td>$345,000,000</td>
<td>$293,400,000</td>
<td>$660,900,000</td>
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<tr>
<td>Change in Annual O&amp;M</td>
<td>$0</td>
<td>$0</td>
<td>$0</td>
<td>$0</td>
<td>$0</td>
<td>$100,000</td>
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<tr>
<td>Annual Cost</td>
<td>$0</td>
<td>$0</td>
<td>$530,000</td>
<td>$11,300,000</td>
<td>$9,610,000</td>
<td>$21,750,000</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Economic Impacts of a Breach</th>
<th>31ft</th>
<th>25ft</th>
<th>20ft</th>
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<tbody>
<tr>
<td>Direct Economic Impacts</td>
<td>$2,415,764,000</td>
<td>$1,453,393,000</td>
<td>$711,407,000</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Expected Annual Economic Impacts</th>
<th>Annual Economic Damages</th>
<th>Cost/Benefits Analysis</th>
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<tbody>
<tr>
<td></td>
<td></td>
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<tr>
<td>Annual Economic Damages</td>
<td>$172,000</td>
<td>$172,000 $5,000 $5,000 $4,000</td>
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<tr>
<td></td>
<td></td>
<td>Net Economic Cost (Change in Annual Cost - Change Economic Damages) $530,000 $11,133,000 $9,443,000 $21,582,000</td>
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<tr>
<td></td>
<td>Benefit Cost Ratio (BCR)</td>
<td>0.00 0.01 0.02 0.01</td>
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<tr>
<td></td>
<td>CSSL (Net Cost/Change in CSSL)</td>
<td>$8,280,000,000 $105,530,000,000 $89,510,000,000 $202,850,000,000</td>
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</tbody>
</table>
### HERBERT HOOVER DIKE - EVALUATION

<table>
<thead>
<tr>
<th>CIZ</th>
<th>Segment</th>
<th>Alternative 1</th>
<th>Alternative 2</th>
<th>Alternative 3</th>
<th>Alternative 4</th>
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</thead>
<tbody>
<tr>
<td>Solution</td>
<td></td>
<td>Cutoff-Wall</td>
<td>Cutoff-Wall</td>
<td>Cutoff-Wall</td>
<td>Pumped Internal Drainage System</td>
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<td></td>
<td>4</td>
<td>No Action</td>
<td>$83,100,000</td>
<td>$83,100,000</td>
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<td></td>
<td>5-2</td>
<td>$1,500,000</td>
<td>$16,800,000</td>
<td>$16,800,000</td>
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<td></td>
<td>5</td>
<td>No Action</td>
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<td>$41,600,000</td>
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<td></td>
<td>6</td>
<td>No Action</td>
<td>$86,400,000</td>
<td>$86,400,000</td>
<td>$157,700,000</td>
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<td></td>
<td>7</td>
<td>No Action</td>
<td>$22,400,000</td>
<td>$22,400,000</td>
<td>$41,200,000</td>
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<td></td>
<td>8</td>
<td>$14,700,000</td>
<td>$14,700,000</td>
<td>$14,700,000</td>
<td>$28,800,000</td>
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<tr>
<td></td>
<td>9</td>
<td>No Action</td>
<td>$80,200,000</td>
<td>$28,400,000</td>
<td>$168,400,000</td>
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<tr>
<td>CIZ B</td>
<td>12</td>
<td>$30,000,000</td>
<td>$63,000,000</td>
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<tr>
<td></td>
<td>13</td>
<td>$1,500,000</td>
<td>$11,700,000</td>
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<td>$23,000,000</td>
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<tr>
<td>Totals (ALARP Depth)</td>
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<td>$47,700,000</td>
<td>$419,900,000</td>
<td>$324,900,000</td>
<td>$792,100,000</td>
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<tr>
<td>Cost increase 15 to 20%</td>
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<td>Totals (Minimal Design Depth)</td>
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<td>$47,700,000</td>
<td>$361,700,000</td>
<td>$280,700,000</td>
<td>$823,784,000</td>
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</tbody>
</table>

**Keys:**
- CIZ D-G dropped out
- $300M vs $2.5B
- Met individual and societal risk
- ALARP to account for uncertainty
- Does not meet design standards for exit gradient
Questions?