Methods to mitigate internal erosion risks in existing embankment dams
Seepage vs. Internal Erosion

• In general, mitigating for internal erosion means mitigating for potentially harmful seepage flows

• However, it is critical to understand that the focus should not necessarily be to reduce seepage but rather to reduce the potential for internal erosion

• This seems obvious, but there are examples in failure case histories where a focus on treating seepage actually worsened the potential for internal erosion
Two Basic Types of Internal Mitigation Measures

• **Seepage control**
  - Designed to collect or direct seepage into engineered features where it can be controlled to minimize adverse behavior such as high gradients, unfiltered exits, etc.

• **Seepage reduction**
  - Designed to reduce seepage by means of extending the seepage path through the use of vertical or horizontal barriers and thus reduce gradients and flows
Seepage Control Measures

- Internal filters and drains
- Toe drains
- Drainage trenches at downstream toe
- Relief wells
- Horizontal drains
- Drainage galleries or tunnels
- Filter envelopes around conduits
Example Filter and Drain Modification (with processed sands & gravels)

- Failure mode associated with internal erosion through the dam and potentially from dam into foundation
  - Dam immediately upstream of a large city did not have original chimney filter nor any modern foundation treatment measures

- Modification
  - Two-stage chimney filter/drain of processed sand and gravel, as well as foundation filter and overlying seepage berm
Example Filter and Drain Modification (with processed sands & gravels)
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(with processed sands & gravels)
Example Filter and Drain Modification (processed sands & geosynthetics)

- Failure mode associated with internal erosion through the dam
  - Embankment was discovered to have transverse crack through nearly full height, with openings up to 5 cm

- Modification
  - Chimney filter consisting of geosynthetic filter/drain overlain by processed sand filter, including horizontal drain and toe drain
Example Filter and Drain Modification (processed sands & geosynthetics)
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Example Downstream Drainage Trench (using biodegradable slurry)

• Failure mode associated with internal erosion through the dam and/or foundation (along foundation contact)
  – Re-worked moraine and outwash deposits in foundation may not have been completely removed during construction

• Modification
  – Vertical interceptor filter trench to bedrock (sand installed with biodegradable slurry trench), chimney filter, and filtered downstream toe drain and berm
Example Downstream Drainage Trench (using biodegradable slurry)
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Seepage Reduction Measures

- Slurry trench cutoff walls
- Sheet pile walls
- Secant pile cutoff walls
- Grout curtains
- Upstream blankets
Cutoff Wall Locations
Example Cutoff Wall (using soil-cement backfill)

• Failure mode associated with internal erosion through the foundation
  – Excessive downstream seepage, with signs of increasing flows with time

• Modification
  – Vertical cutoff wall installed at upstream toe, tied into embankment core and backfilled with a mixture of soil, bentonite, and cement
Example Cutoff Wall (using soil-cement backfill)
Example Cutoff Wall (using soil-cement backfill)

Soil-Bentonite Construction

Backfill Slope
6-10:1

Long trench and dozing backfill creating sloping backfill
Concerns with the material setting prior to completion

Panel Construction

THEREFORE

Determined Panel excavation method would be only way to assure good product
Example Cutoff Wall (multiple trenching methods)

Chisel

Clamshell

Rock Mill
Example Cutoff Wall (using soil-cement backfill)
Example Cutoff Wall (using soil-cement backfill)
Example Upstream Horizontal Blanket (using geomembrane)

- Failure mode associated with internal erosion through a solutioned foundation bedrock unit
  - Sinkhole had been discovered upstream in reservoir

- Modification
  - Horizontal impermeable blanket consisting of geomembrane with soil cover, placed over upstream exposure of bedrock unit of concern
Example Upstream Horizontal Blanket (using geomembrane)
Example Upstream Horizontal Blanket (using geomembrane)

Approximate limits of upstream blanket
Example Upstream Horizontal Blanket (using geomembrane)
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Example Upstream Horizontal Blanket (using geomembrane)
Selection of a Preferred Alternative

- Selection of a seepage control alternative or a seepage reduction alternative can depend on several factors
  - Cost*
  - Degree of risk reduction*
  - Construction risks
  - Length of construction
  - Temporary loss of project benefits
  - Constructability

* Often the most important considerations
Selection of a Preferred Alternative

• The preferred alternative is usually based on a consideration of all these factors, and requires careful deliberation

• The paper includes a table that lists:
  – Mitigation methods
  – Technical advantages
  – Technical disadvantages
  – Construction considerations
  – Relative construction costs
<table>
<thead>
<tr>
<th>Mitigation Method</th>
<th>Technical Advantages</th>
<th>Technical Disadvantages</th>
<th>Construction Considerations</th>
<th>Construction Cost</th>
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</table>
| Internal filter/drain  | Can include multiple stage filter/drain  
Exposes materials (can see potential issues)  
Can tie to monitoring system (toe drain) | May require lowering of reservoir  
Typically requires slope steepening, which can reduce slope stability during construction  
Employ standard earthwork practices | Moderate cost |
| Toe drain              | Permits means of monitoring seepage  
Can include multiple stage filter/drain | Cannot provide drainage for deep seepage  
Typically easy to construct | Generally low cost |
| Drainage trench        | Increased depth over toe drain  
Lessens or eliminates need for dewatering | Limited to one stage filter/drain  
Will likely need to provide for trench stability (bracing, slurry trench, etc.) | Generally low cost |
| Relief wells           | Can reduce pressures in deeper aquifers  
Can design filter pack to prevent piping | Requires periodic maintenance  
Not a “continuous” feature | Generally low cost |
| Horizontal drains      | Can be an effective measure at an existing facility | Requires particular attention to filtering  
Can be constructed in both soil and rock  
Often need many drains | Low to moderate cost |
| Drainage gallery       | Can be a means of reducing pressures at different locations beneath a facility (during original construction) | Requires particular attention to filtering  
Generally has limited application at existing facilities  
Can use tunnel or concrete conduit  
Requires drilling in a confined space | Moderate to high cost |
| Conduit filter envelope| Provides filtering at a location that has traditionally been problematic | May lose capability to evacuate reservoir during construction period  
May require removal of an existing conduit section to construct filter below the conduit | Generally low cost; could be moderate if it requires extensive excavation at existing dam |
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<tr>
<td>Slurry trench cutoff wall</td>
<td>Can construct while reservoir is full</td>
<td>Creates high gradients at bottom/ends of wall Potential for uncontrolled slurry loss</td>
<td>“Blind” operation Requires specialty contractor Trench stability needs attention May need a special detail to tie into existing structure</td>
<td>Generally high cost</td>
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<td>Sheet pile wall</td>
<td>Simple, low cost solution</td>
<td>May have gaps or “windows” where seepage may concentrate</td>
<td>Problematic in coarse-grained soils Presence of water can lead to corrosion issues</td>
<td>Generally low cost</td>
</tr>
<tr>
<td>Secant pile wall</td>
<td>At relatively shallow depths, good confidence that wall is continuous</td>
<td>With deep walls, can be difficult to maintain vertical alignment, which could create gaps</td>
<td>Requires specialty contractor May need a special detail to tie into existing structure</td>
<td>Moderate cost</td>
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<tr>
<td>Soil mixing or jet grouting</td>
<td>Can construct while reservoir is full</td>
<td>May have “windows” – less likely to be continuous than other wall types Generally limited to downstream area (unless drilling through embankment)</td>
<td>Requires specialty contractor “Blind” operation</td>
<td>Moderate cost</td>
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<tr>
<td>Grout curtain</td>
<td>Have used this technique for decades</td>
<td>May have “windows” Grout can degrade Drilling through embankment may cause hydraulic fracturing</td>
<td>Need to carefully monitor grout pressures “Blind” operation</td>
<td>Low to moderate cost</td>
</tr>
<tr>
<td>Upstream blanket</td>
<td>Can reduce seepage at sites where vertical walls are impracticable</td>
<td>Requires lowering of reservoir</td>
<td>Can use natural or geosynthetic products</td>
<td>Generally low cost</td>
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Selection of a Preferred Alternative

• A personal preference, if all else is equal, would be seepage control
  – Usually features standard earthwork construction methods
  – Uncovers the embankment and/or foundation and allows one to view existing conditions
  – Enhances installation of monitoring devices
  – Less likely to lead to concentrated gradients as seen in a cutoff wall

• Remember the fundamental precept of “First, do no harm”
Thank you for your attention