MSHA’s Review of Impoundment Plans

Kelvin K. Wu, Ph.D, P.E.  Chief, Mine Waste and Geotechnical Engineering Division, Pittsburgh, PA

Harold L. Owens, P.E.  Supervisory Civil Engineer, Coal Mine Safety and Health District 4, Mt. Hope, WV

John W. Fredland, P.E.  Civil Engineer, Mine Waste and Geotechnical Engineering Division, Pittsburgh, PA
MSHA Jurisdiction

- 860 Impoundments at Coal Mines
- 695 Impoundments at Metal/Non-metal Mines
Regulations

• Metal/Non-metal Mines
  – 30 CFR Sections 56.20010 and 57.20010.

• Coal Mines
  – 30 CFR Section 77.216 and 77.217.
Present coal standards:

Promulgated following the Buffalo Creek coal-waste dam failure, February 26, 1972, in which 125 people died and over 4000 were left homeless.
Requirements in Coal include:

- Prior to construction, obtain MSHA approval of design plans & construction specifications.

- Have a “Qualified Person” examine the impoundment at least every seven days.

- Provide an annual certification by a P.E. that impoundment was constructed, operated, and maintained, according to approved plan.
Plan Review Process

• Plan submitted to MSHA District Office.
• Plan either forwarded to Technical Support for review, or reviewed by District staff.
• If deficiencies are found, letter sent to company explaining issues that need to be resolved.
• Meetings held, and site visits made, when useful to resolve problems.
• Once issues resolved, approval letter issued by the District Manager.
Design Storms

• Impoundments must be capable of handling large storms without failure or significant damage.

• Dams with high-hazard potential - meaning loss of life is likely in the event of failure - must be designed to handle the probable maximum flood (PMF).

• Common Review Issue: Use of a design storm less than the PMF must be substantiated with a conservative dam-break analysis.
Flood Routing of Design Storm

• Plans need to show that, when the design storm occurs:
  – Adequate minimum freeboard will be maintained, usually at least 3 feet, so that overtopping does not occur.
  – The discharge will not cause significant erosion or structural damage.
  – The inflow will be discharged quickly enough to allow for consecutive storms (i.e. 90% of storm runoff drawn down within 10 days).

• Common Review Issues:
  – All flood-routing parameters must be substantiated.
  – The entire watershed must be illustrated on a topographic map.
  – Copies of input and output files for computer runs must be provided.
  – Helpful if input files are also provided in electronic format.
Design of spillways and decants:

Decant pipe issues include flow capacity, durability, corrosion protection, joint details, water-tightness, bedding, backfill, structural design, thrust blocks, seepage-control, and trash-rack design.

Spillway issues include discharge capacity, flow velocities, channel freeboard, erosion resistance, uplift / drag forces, and liner anchorage and durability.
Site conditions need to be investigated to determine material properties & identify potential failure modes. An experienced geotechnical engineer should direct the exploration & testing program.

Common Review Issues:

- Locating mine workings and auger holes;
- Obtaining appropriate sized samples for testing;
- Use of appropriate testing procedures;
- Provisions to verify coal waste properties over long design life.
Plan reviews include checking the sampling and testing done to determine shear strengths, and verifying that appropriate slope stability analyses were conducted.

Common Review Issues:
• Location of embankment saturation level used in analysis;
• Investigation of sliding-wedge failures where a weak layer is present.
Upstream Construction Issues…

Pushouts for upstream construction result in the underlying loose, saturated fines becoming part of the “structural” portion of the embankment.

Slope failure can result from elevated pore-water pressures caused by constructing the pushout to rapidly, or by a seismic event.
Compacted Embankment

Settled Fines

Upstream Construction

Simplified Cross-Section Showing Potential Failure Surface Through Fines.

Common Review Issues:

- Effect on stability of excess pore-water pressures induced by upstream pushouts;
- Liquefaction and loss of strength of the settled fines during a seismic event;
- Stability and deformation of the embankment during seismic event;
- Appropriate sampling and testing for dynamic properties or undrained shear strength;
- Appropriate ground-motion parameters (acceleration, duration, frequency) for the site.
- The overall significantly increased complexity and uncertainty in a seismic analysis.
Common Review Issues:

- Size and location of drains with respect to the embankment saturation level used in design;
- Durability of drainage aggregate;
- Potential for clogging of geotextile filter layers;
- Provisions to prevent damage to geotextiles during and after installation.
Common Review Issues:

• Pipe manufacturer’s design methods typically apply to shallow burial depths;
• Analyses are needed to show adequate levels of safety with respect to wall crushing, buckling, and excessive deflection;
• Methods need to be specified to monitor the performance of pipes to be buried under high fills.
Common Issues:

- Cells are typically kept small enough to keep the site classified as having low-hazard potential.
- If the cumulative cell volume is greater than 20 acre-feet, the site is classified as an impoundment and all of the impoundment design issues need to be addressed.
- Cells work best when the depth of fines is kept shallow, preferably to five feet or less.
Construction Specifications

Common Review Issues:

• Specifications are not complete, not clear, or not consistent within the plan.
• Provisions for quality control during construction not adequately addressed.
• Provisions to verify pertinent engineering properties over time not incorporated.
Common Review Issues:

- Collection of insufficient information to reflect the performance of the site and provide warning of potential problems.
- Lack of provisions to plot and analyze monitoring data in a timely manner.
Mine Workings Near Impoundments

Common Review Issues Include:

• Verifying the location of mine workings.

• Determining the engineering properties and analyzing the behavior of the overburden.

• Evaluating the effects of ground disturbance on the seepage, deformation, and overall safety of the dam.

• Evaluating the potential for a breakthrough into the mine workings.

• Evaluating the potential for the progressive deterioration in the long-term.

• Increased uncertainty, requiring that compensating safety features be incorporated in the design.
Example of Mine Map Inaccuracy:

- The table below shows the results of drilling performed at an impoundment site in 2001. The underground mining had been conducted from 1985 to 1995. These types of discrepancies between the “mapped” and “actual” amount of barrier could have serious implications in the safety of an impoundment.

- Since 1995, there have been over 100 inundation accidents at coal mines.

<table>
<thead>
<tr>
<th>Expected horizontal distance to workings, based on mine map, feet.</th>
<th>Actual horizontal distance to works based on drilling, feet.</th>
<th>Discrepancy, i.e. based on horizontal drilling, workings actually this much closer or farther from highwall than shown on mine map.</th>
</tr>
</thead>
<tbody>
<tr>
<td>40</td>
<td>37.5</td>
<td>2.5 feet closer</td>
</tr>
<tr>
<td>122</td>
<td>92</td>
<td>30 feet closer</td>
</tr>
<tr>
<td>137</td>
<td>89</td>
<td>48 feet closer</td>
</tr>
<tr>
<td>27</td>
<td>67</td>
<td>40 feet farther</td>
</tr>
<tr>
<td>67</td>
<td>41</td>
<td>26 feet closer</td>
</tr>
</tbody>
</table>
Lessons from Slurry Breakthroughs

• Research all available information on geologic and mining conditions at the site.
• Have a qualified engineer or geologist walk and examine the entire impoundment site for signs of mining or mining effects.
• Verify the location of coal outcrops, mine openings, auger holes, and underground workings.
• Perform sufficient exploration and testing to determine the geologic conditions and identify potential failure modes.
• Collect sufficient information to evaluate the consequences of a breakthrough.
• Have the conditions evaluated by a profession engineers knowledgeable of dam safety, subsidence, pillar strength, etc.
• Identify and evaluate the margin of safety for each potential failure mode.
• Ensure that worst case conditions are evaluated.
• Incorporate measures to provide strength, control seepage, and reduce hydrostatic pressure, as appropriate, in the areas of potential breakthroughs.
• Provide for monitoring of the conditions needed to show whether the measures taken are working as intended, and to warn of potential problems.
Some Breakthrough Prevention Measures

- Where overburden properties indicate that the potential for sinkholes or subsidence cracks exists, provide a positive method to prevent them from developing, or locate the impoundment far enough away so as not to be affected by them.

- Positive support can be provided by backfilling portions of the mine workings.

- Fill barriers can be constructed around the perimeter of basins to keep the impoundment from being over or near potential breakthrough areas.
  - Internal drainage provisions are needed in such barriers to collect seepage, reduce hydrostatic pressures on the outcrop, and discharge seepage to a safe point.
  - The thickness of a barrier of compacted fill should not be considered a substitute for the amount of “solid cover” needed to prevent sinkhole development.

- The use of slurry cells is a method to reduce the chances and consequences of a breakthrough.

- Critical parameters, such as water discharge, piezometric levels, and movement, should be monitored to show whether or not a breakthrough prevention design is performing as intended.
Seismic Stability Evaluation

- Examine worst-case scenarios – complete loss of strength in liquefiable materials.
- Design Earthquake Selection
- Dynamic Response Analysis
- Liquefaction Resistance Assessment
- Permanent Deformation Analysis
- Design Features to Mitigate Seismic Risk
Examine Worst-case Scenarios

• Consequences of complete loss of strength in potentially-liquefiable materials.
• Can the embankment be staged in such a way to prevent catastrophic failure, without relying on any shear strength in the liquefiable zones?
Design Earthquake Selection

• Low seismicity exists in many mining areas of the U.S. (i.e. the Appalachian Coalfields)
  – No recorded time histories of strong ground motions - creates difficulty in:
    Predicting Maximum Credible Earthquake (MCE)
    Convincing companies and consultants of credible risk
  – Uncertainties in attenuation characteristics in these areas, due to lack of strong motion data.
  – Deterministic vs. pseudo-probabilistic approach
Dynamic Response Analysis

• Earthquake Time History
  – Synthetic time history scaled to ground acceleration
  – Records from other earthquakes scaled to ground acceleration
• Dynamic Response Properties (shear modulus and damping ratio)
  – Field testing – shear wave velocity
  – Lab testing – resonant column
  – Normalized Modulus Degradation Curves
    • Are curves developed for natural soils valid for mine refuse?
• Modeling – 1-D, equivalent linear (SHAKE)
Liquefaction Resistance

- Empirical Approach
  - SPT, CPT, Vane Shear

- Laboratory Testing
  - Cyclic Triaxial
    - Difficulties in sampling liquefiable materials
    - Uncertainties introduced with remolding
  - Undrained Steady State Strength Testing
    - Extreme care in sampling – Fixed Piston Sampler
    - Precise void ratio tracking – throughout sampling, transporting, extruding, and testing

- Post-Liquefaction Assessment
  - Based on Steady State Line (SSL)
Permanent Deformation Analysis

- Newmark (or similar) Analysis
- Will the embankment retain the contents of the pool in its deformed condition?
- Repairable damage is acceptable if catastrophic failure can be prevented.
Design Features to Minimize Seismic Risks

• Embankment staging to minimize and control upstream construction
• Additional Embankment Width
• Internal Drainage
• Significant Freeboard
• Emergency Action Planning
• Follow-up field testing during later stages of construction
The Goal of MSHA’s Impoundment Program: Help ensure that impoundments are designed, constructed, operated and maintained in a manner that protects the safety of miners and the public.