Liner system design for tailings impoundments and heap leach pads

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TAILINGS & MINE WASTE 08, VAIL
Liner Systems

- Liner systems
  - Environmental containment of process solutions
  - Enhances solution recovery and management

- Heap leach pads
  - Dedicated lined pads w/ external solution ponds
  - Valley leach facilities w/ internal solution storage
  - On/off pads w/ active cells and external solution ponds
  - Hybrid pads (internal and external solution storage)

- Tailings impoundments
  - Internal solution collection
  - Enhanced consolidation
  - Solution management
Modern Liner System Design

- Blend of natural and synthetic components.
- Integration of geosynthetics
- Designed to achieve desired level of performance under anticipated loads.
- Experience has shown there is close interaction between the various components of the liner system.
- Liner system design approach should focus on the interaction and compatibility between components.
Liner System Design Considerations

- Lining systems in mining environment exposed to harsh conditions:
  - High loads (HLPs designed to exceed 4 MPa)
  - Solar radiation
  - Steep grades
  - High seismic loads
  - Ore truck traffic
  - Ore processing solutions
HLP Liner System Design
Typical Liner System Components

- Overliner Layer
  - Drainage and protection layers
  - Solution collection piping
  - Air injection piping

- Geomembrane liner
- Liner bedding soil
- Prepared foundation

- Single-Composite Liner System

- Upper geomembrane liner
- Leak detection layer
- Lower geomembrane liner

- Double-Composite Liner System
Liner System Components
Liner System Components

- Foundation
- Liner bedding
- Geomembrane liner
  - HDPE, LLDPE, PVC, etc
- Overliner
  - Protection layer
  - Drainage layer
  - Solution collection pipes
  - Air injection pipes
HLP Inter-Dependent Design

- Environmental containment
- Solution collection
- Heap stability
Environmental Containment

- Liner bedding
  - Hydraulic properties
  - Compaction characteristics
  - Physical characteristics
- Foundation
  - Settlement affecting GM performance
- Geomembrane
  - Mechanical properties
- Overliner
  - Physical characteristics
Solution Collection

- **Overliner**
  - Hydraulic properties (solution flow)
  - Mechanical characteristics under load (solution flow and pipe support)
  - Geochemistry (reaction with leach solutions)
  - Physical characteristics

- **Solution Pipes**
  - Mechanical properties under load
  - Interaction with drainage materials

- **Pad grading**
  - Sloped for solution collection and heap stability
Heap Stability

- Liner bedding
  - Residual interface friction between liner and bedding
  - Internal shear strength
- Overliner
  - Residual interface friction between liner and overliner
  - Internal shear strength
- Ore loading
- Pad grading
- Internal solution levels
Design Flow Chart – Liner Bedding

Leach Pad
Preliminary Design

Hydraulic Properties
Pass

Interface Shear
Pass

Fail

Change Material Specification

Change GM Specification

Change Grading Plan

Change Material Specification

Liner Bedding Soil Design Flow Chart

Overliner Design Flow Chart

Feedback from Overliner Flow Chart
Design Flow Chart – Overliner

Liner Bedding Soil Input

- Hydraulic & Geochemical Properties
  - Pass: GM Puncture Testing
  - Fail: Change Material Specification

GM Puncture Testing
- Pass: Interface Shear
- Fail: Change GM Specification

Interface Shear
- Pass: Change Grading Plan
- Fail: Change Material Specification

Pipe Support
- Fail: Change Material Specification
- Pass: Change Pipe Specification

Detailed Design

Feedback to Liner Bedding Soil Flow Chart

Overliner Flow Chart
Solution Collection Pipes

- Traditionally, design equations based on the performance of “stiff” pipe (e.g. pipe materials have a high stiffness compared to surrounding materials)
- Geopipes are generally less stiff than surrounding materials, therefore traditional equations not really applicable
- Pipe design methods need to consider pipe flexibility and interaction between pipe and surrounding materials
Pipe Deformation

Note: Pipe deformation is a function of both pipe stiffness and envelope quality.

After Watkins and Reeve, 1979
Soil Arching

Applied Surface Load

Soil arching reduces stress transfer onto the pipe. The magnitude of the arching affect is a function of the pipe stiffness and pipe envelope properties.
Pipe Response
Soil Arching – Stress Reduction

Stress reduction at pipe due to soil arching

(Stress reduction at pipe due to soil arching)

Geostatic Stress
Vertical Stress
Horizontal Stress

(after Adams et al. 1988)
Pipe Design

- Use design methods for flexible conduits [Burns and Richards (1964) and Höeg (1968)]
- Important: Test the one-dimensional compression (stress vs strain) of the drainage material.
  - Governs the stress transfer to the pipe.
- Consider both Corrugated and Solid PE pipe to meet desired performance
- Thickness of drainage layer does affect pipe performance under load
TSF Liner System Design
Typical Liner System Components

Overliner Layer:
- Drainage and protection layers
- Drainage piping

Geomembrane liner

Liner bedding soil

Prepared foundation

Single-Composite Liner System
Liner System Components

- Foundation
- Liner bedding
- Geomembrane liner
  - HDPE, LLDPE, PVC, etc
- Overliner
  - Protection layer
  - Drainage layer
  - Drainage pipes
Important Design Considerations

- Strain on GM from loading due to foundation settlement
- Compatibility of liner bedding material with process solution chemistry
- Long-term exposure of GM to solar
- Maximum hydraulic head on liner system
- Leak detection/collection requirements
- Tailings delivery
  - Discharge onto GM may cause damage to liner
GM Selection
GM Performance

- Based on experience
- Rough correlation to liner-load test
Liner-Load Testing

**Diagram Labels:**
- Reaction Frame
- Hydraulic Ram
- Loading Plate
- Steel Vessel

**Textual Descriptions:**
- **Overliner - Coarse particles placed against liner**
- **Geomembrane**
- **Underliner - Compacted to field specifications. Maximum particle size placed on surface of compacted surface**
### GM Liner Selection Chart

<table>
<thead>
<tr>
<th>Foundation</th>
<th>Liner Bedding</th>
<th>Overliner</th>
<th>Effective normal stress (MPa)§</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>&lt;0.5</td>
</tr>
<tr>
<td>Firm or high stiffness</td>
<td>Coarse-grained</td>
<td>Coarse-grained 2mm LLDPE or HDPE</td>
<td>2mm LLDPE or HDPE 2.5mm LLDPE or HDPE</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Fine-grained 1.5mm LLDPE or HDPE</td>
<td>2mm LLDPE or HDPE 2.5mm LLDPE or HDPE</td>
</tr>
<tr>
<td></td>
<td>Fine-grained</td>
<td>Coarse-grained 1.5mm LLDPE or HDPE</td>
<td>1.5mm LLDPE or HDPE 2mm LLDPE or HDPE</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Fine-grained 1mm LLDPE or HDPE</td>
<td>1.5mm LLDPE or HDPE 2mm LLDPE or HDPE</td>
</tr>
<tr>
<td>Soft or low stiffness</td>
<td>Coarse-grained</td>
<td>Coarse-grained 2mm LLDPE</td>
<td>2mm LLDPE 2.5mm LLDPE</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Fine-grained 1.5mm LLDPE</td>
<td>2mm LLDPE 2.5mm LLDPE</td>
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</tbody>
</table>
Conclusions 1/2

- Compatibility between the liner system components important for robust design
  - Performance of one component can affect the performance of other components

- Liner system testing and analysis needs to consider all components under the anticipated loading conditions.
  - Static & dynamic loads
  - Geochemistry of solutions
  - Environmental factors
Conclusions 2/2

- Pipe design must use flexible conduit approach.
- Design of drainage materials (particle size, compressibility, and thickness) does affect pipe performance.
- Foundation settlements affect both geomembrane liner and solution pipe performance.
- With proper design, liner systems can perform under very high loads and harsh conditions.
Questions