Interbedded Sand Layers (ISL) Concept for Deep Fines-Dominated Tailings Deposits

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Project information

- This desktop study was Phase 1 of a Shell Canada Energy project completed by Thurber Engineering in 2016.
- The objective was a theoretical / numerical investigation of feasibility of the Interbedded Sand Layers (ISL) concept.
- Phase 1: Desktop study
  - Feasibility and applicability of the ISL concept
  - Development of representative simulation models
  - Identification of critical influential parameters
- The Desktop Study acts as a gate to proceed to the next two phases:
  - Phase 2: Practical aspects of the ISL concept implementation (laboratory and small-scale pilot)
  - Phase 3: Field-scale demonstration – trial ISL deposition
Outline

- ISL concept
- Essential physics for simulations
- Principal factors for ISL concept
- Simulation models
- Parametric analyses of a hypothetical deposition case
- Results
- Implementation Issues
- Directions for further work
- Conclusions of desktop study
Traditional deposition

The drainage path length equal to the deposit thickness.
ISL concept

- Shorten the drainage paths and reduce the total consolidation time
- Provide drainage pathways for quick removal of consolidation-released water out of the deposit
Consolidation time as function of drainage path length

This demonstration model makes use of a simple 1D Terzaghi’s small strain consolidation theory.

<table>
<thead>
<tr>
<th>Case</th>
<th>Reference case</th>
<th>Single drainage</th>
<th>2 drainage layers</th>
<th>3 drainage layers</th>
<th>4 drainage layers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Consolidation time ratio (T / T_{ref})</td>
<td>( \left( \frac{H}{H} \right)^2 )</td>
<td>( \left( \frac{H/2}{H} \right)^2 )</td>
<td>( \left( \frac{H/3}{H} \right)^2 )</td>
<td>( \left( \frac{H/4}{H} \right)^2 )</td>
<td>( \left( \frac{H/5}{H} \right)^2 )</td>
</tr>
<tr>
<td></td>
<td>= 1</td>
<td>= ( \frac{1}{4} )</td>
<td>= ( \frac{1}{9} )</td>
<td>= ( \frac{1}{16} )</td>
<td>= ( \frac{1}{25} )</td>
</tr>
<tr>
<td>Consol. time (yrs)</td>
<td>Assume 200</td>
<td>50</td>
<td>22</td>
<td>13</td>
<td>8</td>
</tr>
</tbody>
</table>

Free-draining top

Free-draining bottom
Essential physics for simulations

- Multi-dimensional water flow:
  in fine tailings essentially vertical; in sand prevailingly horizontal

- One-dimensional deformation:
  dominantly vertical and concentrated in fine layers;
  sand may be assumed incompressible
Principal factors

- Sand-to-tailings hydraulic conductivity ratio: $k_s/k_f$
- Length of drainage layers $L$ (i.e. pond area)
- Sand-to-tailings layer thickness ratio: $H_s/H_f$
## Simulation models

<table>
<thead>
<tr>
<th>Model</th>
<th>Terzaghi-Rendulic</th>
<th>Gibson et al.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Description</td>
<td>Small strain 2D</td>
<td>Finite strain with specific ISL flow boundary conditions</td>
</tr>
<tr>
<td>Water flow</td>
<td>2D plain strain, rigorous formulation</td>
<td>1D axial symmetry, volume averaging</td>
</tr>
<tr>
<td>Deformation (settlement)</td>
<td>1D</td>
<td>1D</td>
</tr>
<tr>
<td>Governing equation variable</td>
<td>Excess pore pressure</td>
<td>Excess pore pressure</td>
</tr>
<tr>
<td>Pond shape</td>
<td>Square-base prism</td>
<td>Cylinder</td>
</tr>
<tr>
<td>Material parameters</td>
<td>Linearized – range of min-max $c_v$</td>
<td>Non-linear $e(\sigma')$, $k(e)$</td>
</tr>
<tr>
<td>Deposition effect</td>
<td>Stacking: $1^{st}$ step = self-weight consolidation, with surcharge load subsequently</td>
<td>Stacking: $1^{st}$ step = self-weight consolidation, with surcharge load subsequently</td>
</tr>
</tbody>
</table>
Input data

- Annual production rate, fine tailings: 3.6 Mt/year of dry solids
- Pond area: 1 km$^2$ (adopted constant over height)
- Deposit thickness (nominal): 75 m
- Nominal rate of rise (RoR): 8 m/year, with filling time of ~9 years
- Tailings types: CC - centrifuge cake SC=50% and ILFT - in-line flocculated tailings SC=37%
Parametric analysis

- End of filling (EOF):
  - Deposit height
  - Average excess PWP dissipation
  - Times to 90% consolidation by:
    - Settlement
    - Excess pore water pressure
  - Differential settlement from EOF to ultimate
  - Storage efficiency: solids and fines
Results for centrifuge cake (CC) 1

Much more settlement during deposition with ISL.
Post-deposition settlement much smaller with ISL – roughly 50% of the settlement of the CC deposit without ISL.

The model based on Gibson et al.
Results for centrifuge cake (CC) 2

The model based on Gibson et al.
## Results for centrifuge cake (CC) 3

<table>
<thead>
<tr>
<th>KPI</th>
<th>1D Reference (No sand layer)</th>
<th>R=200 m (With sand layers)</th>
<th>R=500 m (With sand layers)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Tailings to Sand Thickness</td>
<td>7m : 1m</td>
<td>6m: 2m</td>
</tr>
<tr>
<td>Excess PWP Dissipation EOF (%)</td>
<td>3.3</td>
<td>18.0</td>
<td>30.5</td>
</tr>
<tr>
<td>Time to 90% PWP Dissipation (years)</td>
<td>&gt;200</td>
<td>22</td>
<td>17</td>
</tr>
<tr>
<td>Settlement from EOF-to-ultimate (m)</td>
<td>23.7</td>
<td>12.4</td>
<td>8.4</td>
</tr>
<tr>
<td>Average Solids Content at EOF (%)</td>
<td>50.9</td>
<td>57</td>
<td>59.7</td>
</tr>
</tbody>
</table>

The model based on Gibson et al.
Implementation issues

- Tailings ponds are engineered structures that are operational during construction - the ISL design concept merely shifts focus from the end to the earlier stages of construction.

- Placement of uniform and continuous drainage layers in an operating pond requires non-conventional methods (e.g. sand delivery from pond perimeter to its interior).

- Construction of perimeter drains and management of drained water need to be addressed in further work.

- Effects of the actual shape of a deep deposit - with sloping pit sides – will likely be beneficial, but need to be studied.

- In the presented case of centrifuge cake (CC) the deposit significantly benefited from horizontal drains when pond size was not much larger than approximately 1 km. To keep this performance level for larger ponds, an intermediate vertical drainage system may be required, in addition to perimeter drains.
Directions for further work

- Investigate construction methods for ISL deposits, particularly hydraulic delivery of coarse material from pond perimeter into its interior under usual commercial operation conditions
- Conduct demonstration experiments with gradual progress from laboratory to pilot scale to typical operational conditions, with continuous performance monitoring
- Discuss possible commercial realization of an ISL deposit with planners and operations and identify potential larger-scale issues to investigate
- Consolidate desired features – multidimensional flow, finite strain theory, non-linear material properties - in a comprehensive model
- Delineate application limits for various oil sands tailings types
- Investigate possible synergies with other tailings management strategies and current practices
Conclusions

- Parametric analyses showed theoretical merits of interbedded sand layers and overall significant beneficial impact on consolidation of a deep deposit of fine tailings
- Dramatic increase in the consolidation rate for low-permeability materials (e.g. centrifuge cake)
- Solids and fines storage efficiencies of ISL deposits consistently higher than those of homogeneous deposits of the same tailings
- Post-deposition settlements of ISL deposits much smaller than those of homogeneous deposit. Sand drainage layers accelerate consolidation during deposition, which is beneficial for reclamation design and increases predictability of behaviour of closure landscape