



FLAC Based Modelling of Tailings Deposition and Consolidation

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Outline

- Purposes of geo-modelling of tailings in an impoundment
- State-of-the-practice in tailings modelling
- FLAC-based modelling approach
- Validations of the modelling approach
- Example case

Main Purposes of Tailings Geo-Modelling

Mine operation planning

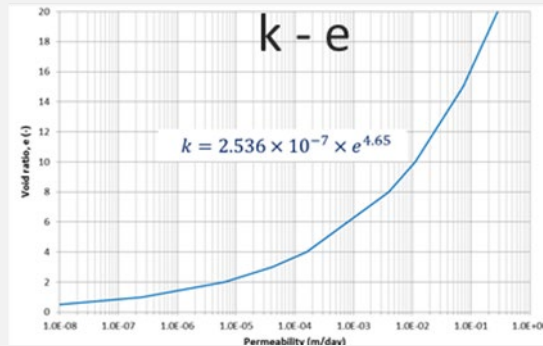
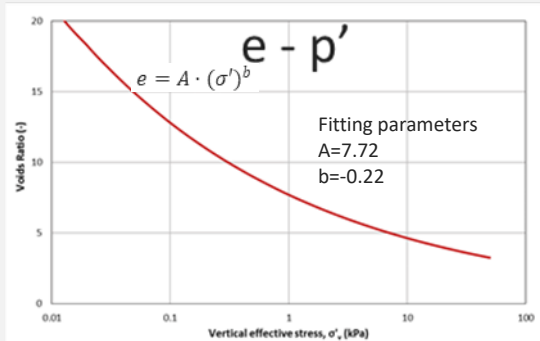
- *To predict capacity of the impoundment for tailings storage (> geometric volume), = function of tailing properties and deposition scheme.*

Mine closure

- To predict surface settlement after rock/sand backfilling;
- To estimate the amount of water to be discharged out of the tailings during consolidation;

Main challenges in modelling tailings deposition

- Continuous tailings deposition during consolidation process.
- Tailings large compressibility at small stress.



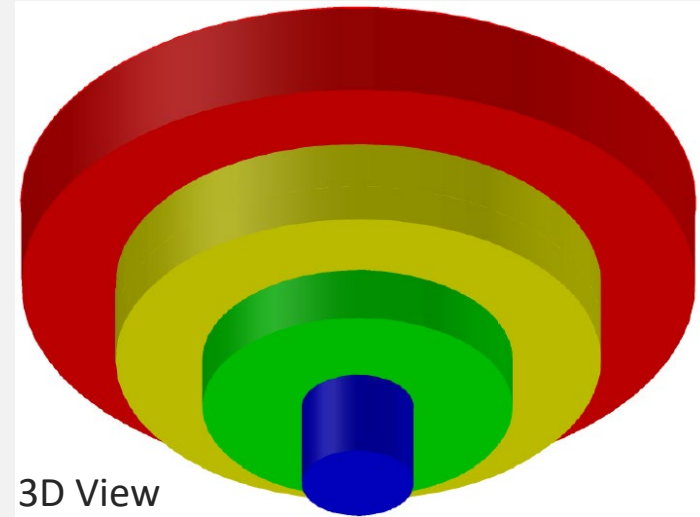
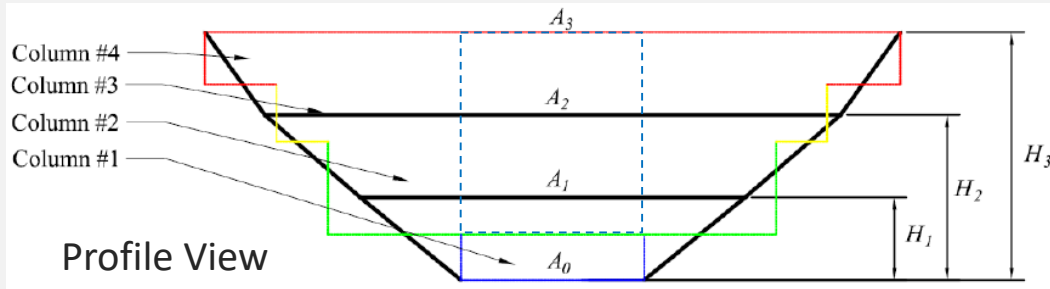
State-of-the-practice

Pseudo 3D Approach (main state of practice)

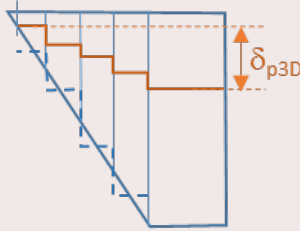
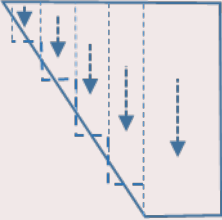
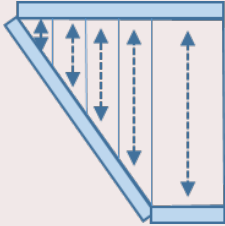
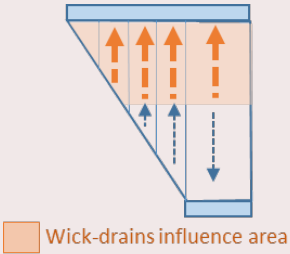
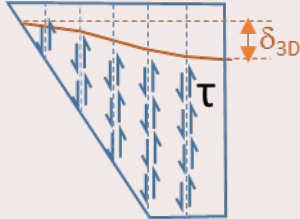
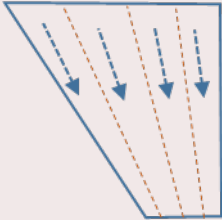
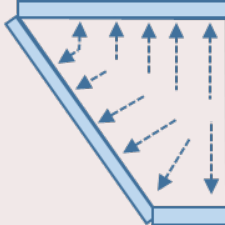
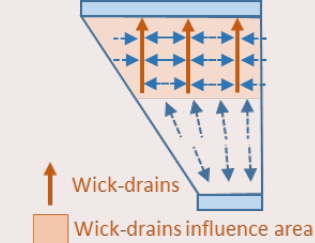
- Based on 1D large-strain consolidation theory
- Uses a series of annulus to model pit geometry

Quasi 3D Approach

- 3D flow analysis
- 1D (Vertical) consolidation



Pseudo-3D Approximation vs. Multi-dimensional Modelling

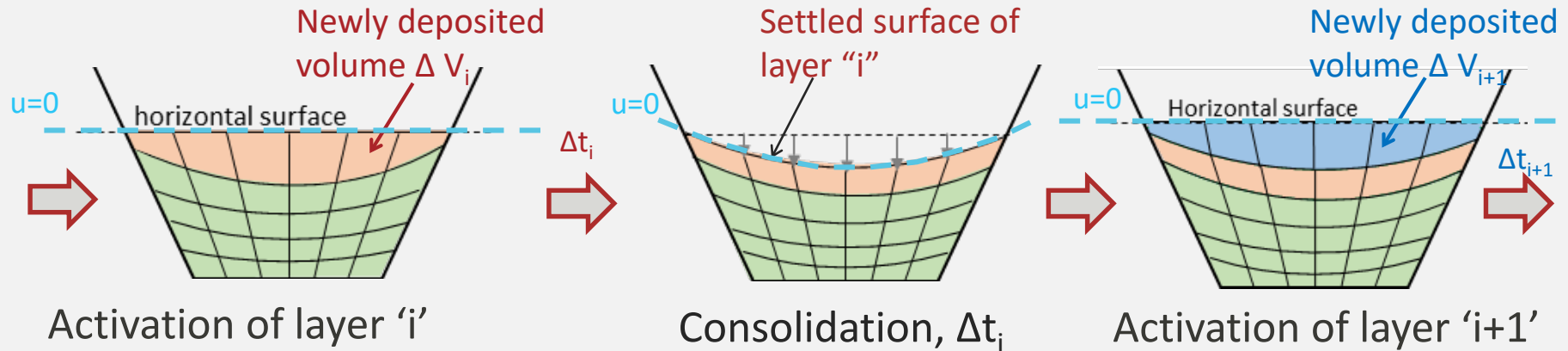
Comparison	Interaction between the columns; $\delta_{p3D} > \delta_{3D}$	Deformation pattern	Non-vertical flow	Modelling of wick drains
Pseudo-3D				
Multi-dimensional modelling (~ Reality)				

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- Purposes of geo-modelling of tailings in an impoundment
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- **FLAC-based modelling approach (Multidimensional 2D/3D)**
- Validations of the modelling approach
- Example case

FLAC-Based Modelling Approach

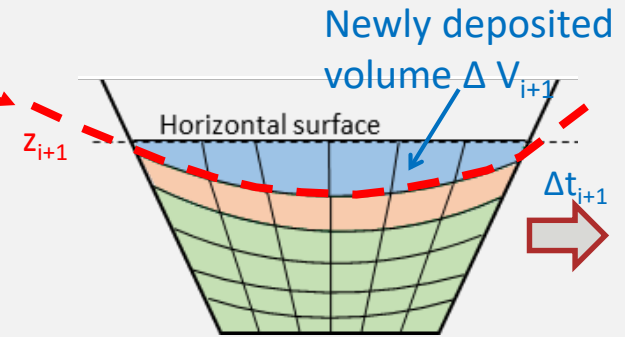
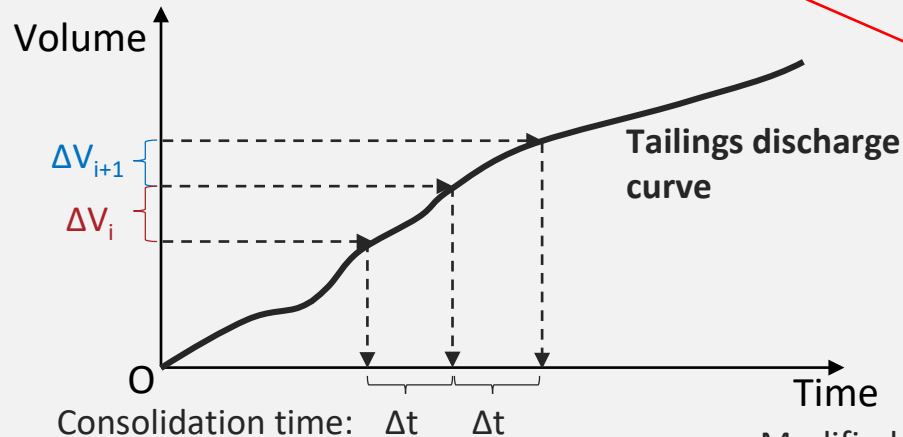
- Modelling gradual tailing deposition (fish subroutine)
 - Staged filling approach: (i) undrained slurry deposition ($\sigma'_v \approx 0$) followed by a (ii) stage of consolidation (under self weight).
 - Update top boundary conditions after each stage of deposition.
 - New level of horizontal surface (z_{i+1}) calculated based on tailing discharge rate (Δv_{i+1}) and actual settled surface.



FLAC-Based Modelling Approach

➤ Modelling of gradual tailing deposition (fish subroutine)

- Staged filling approach: (i) undrained slurry deposition ($\sigma'_v \approx 0$) followed by a (ii) stage of consolidation (under self weight).
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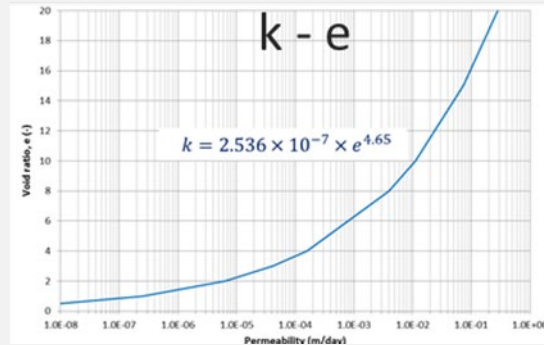
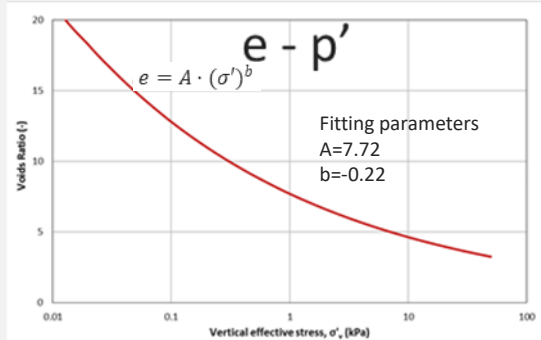
Activation of layer 'i+1'

Modified from: Zhou et al (2019)

FLAC-Based Modelling Approach

➤ Constitutive model

- Non-linear relationships of e - σ' and k - e implemented in the Mohr-Coulomb model in FLAC.
- Voids ratio (e) for each element computed according to the volumetric strain (large strain) → update on the density, tangent stiffness and permeability.



$$M = \left(\frac{(1+e_0)}{A \cdot b} \right) \cdot \left(\frac{e}{A} \right)^{\left(\frac{1}{b} - 1 \right)}$$

M = Tangent constrained modulus

e_0 = void ratio at deposition

e = void ratio $< e_0$

A and b = fitted parameters as per e - σ'_v relationship

$$K = \frac{\delta \varepsilon_v}{\delta p} = \frac{M \cdot (1 + \nu)}{3 \cdot (1 - \nu)}$$

K = tangent bulk modulus

$\delta \varepsilon_v$ = incremental volumetric deformation

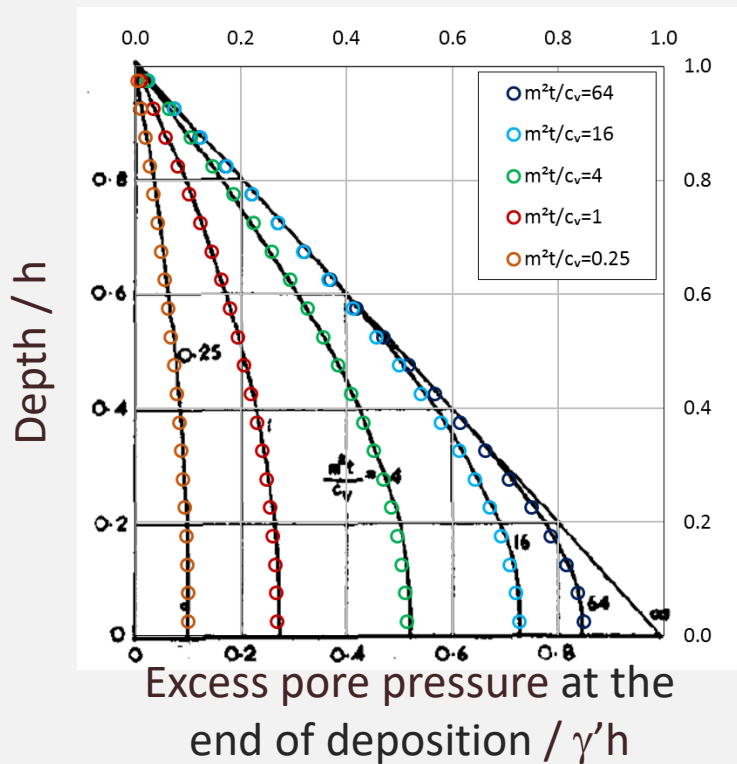
δp = incremental isotropic stress

ν = Poisson ratio

Outline

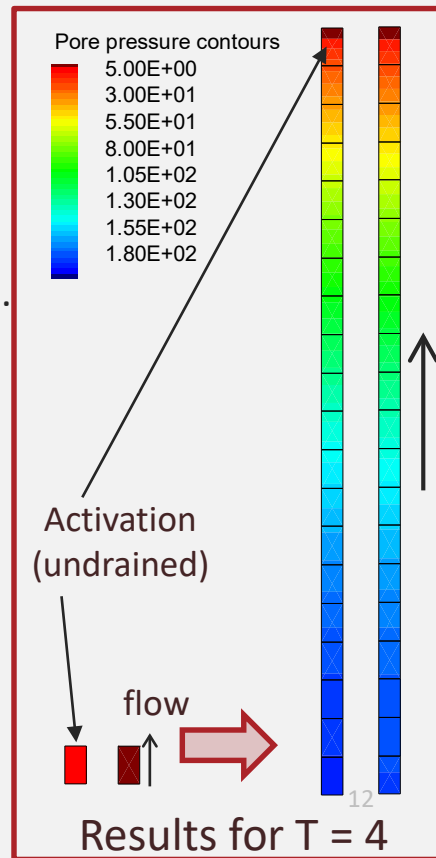
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Validation of the deposition process (against Gibson, 1958): Consolidation in a clay layer increasing in thickness with time



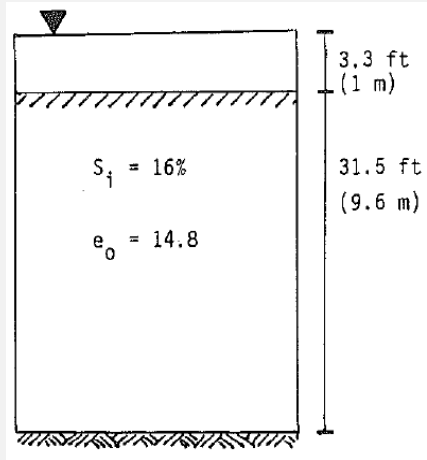
Modified from: Amodio et al (2019)

- $T = m^2 t / c_v$ = normalised deposition rate.
- m = deposition rate.
- t = total deposition time.
- c_v = coefficient of consolidation.
- h = thickness at the end of deposition.
- γ' = soil/tailings effective unit weight.

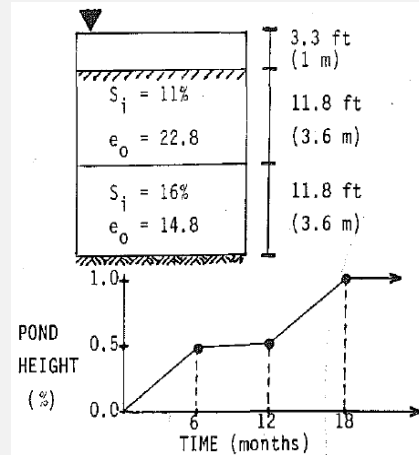


Comparisons with Predictions in Townsend and McVay (1990)

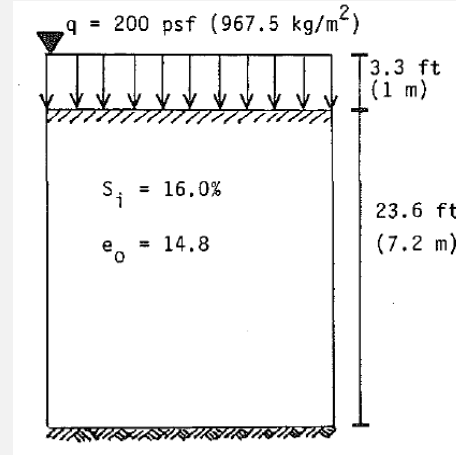
Scenario A



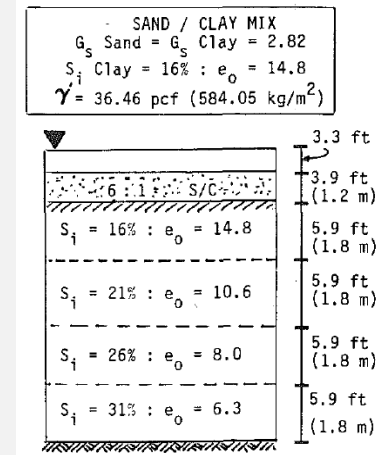
Scenario B



Scenario C



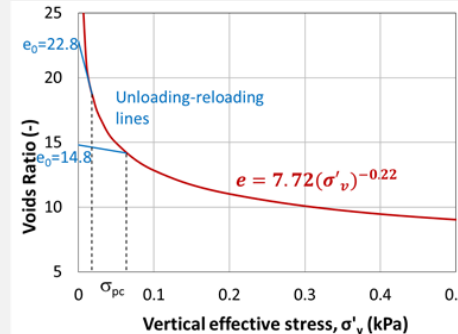
Scenario D



Clay properties

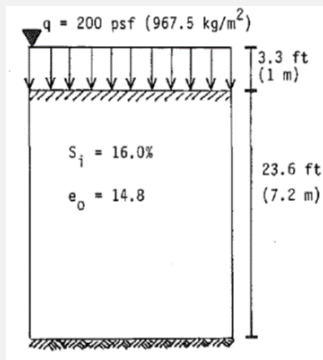
$$e = A(\bar{\sigma})^{-B}(\text{kPa}) \Rightarrow e = 7.72(\bar{\sigma})^{-0.22} \dots\dots$$

$$k = c(e)^D(\text{m/d}) \Rightarrow k = (0.2532 E - 06)e^{4.65}$$

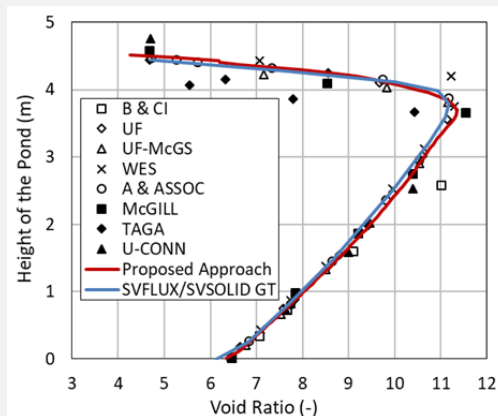


Validation against Townsend and McVay (1990)

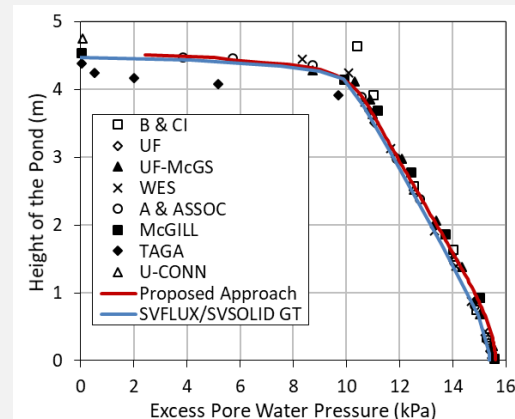
Scenario C



Results after 1 year

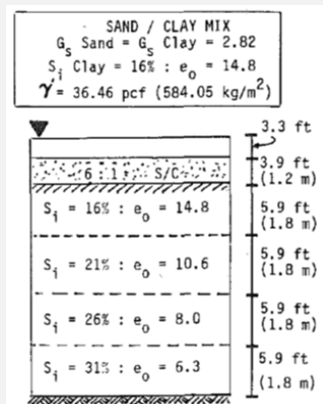


Void Ratio

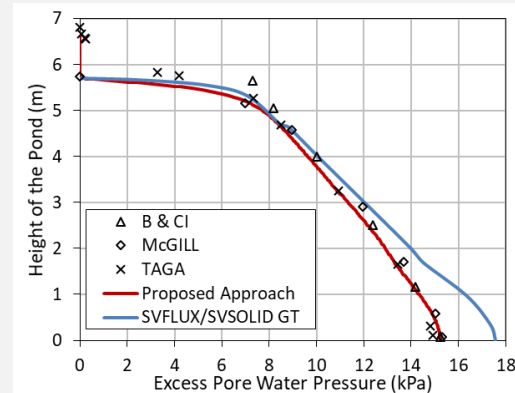
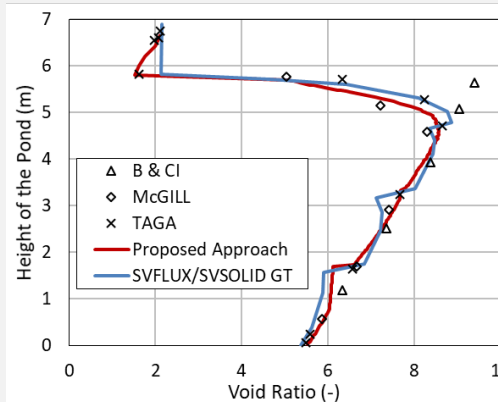


Excess Pore Pressure

Scenario D



Results after 1 year



Modified from: Amodio et al (2019)

Scenario B

JOB TITLE : Verification: Townsend and McVay (1990), Scenario B

FLAC (Version 8.10)

LEGEND

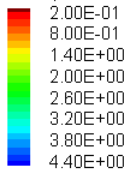
2-Sep-19 15:24

step 96

-1.000E-01 <x< 3.800E+00

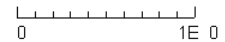
-1.000E-01 <y< 3.800E+00

Pore pressure contours

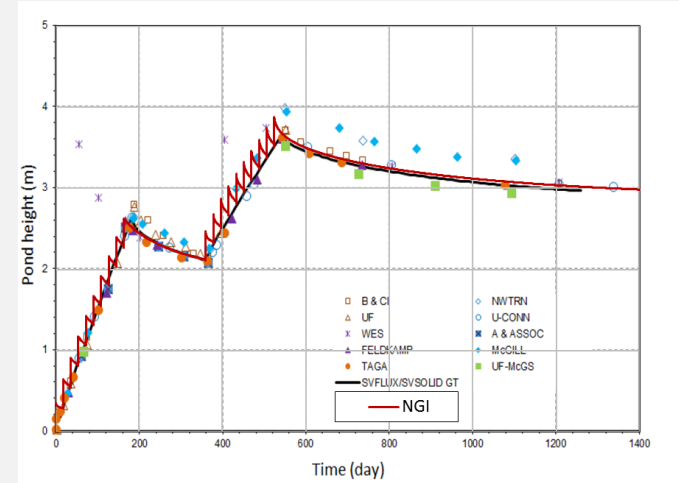
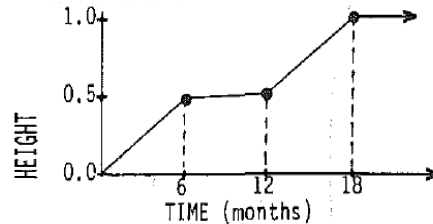
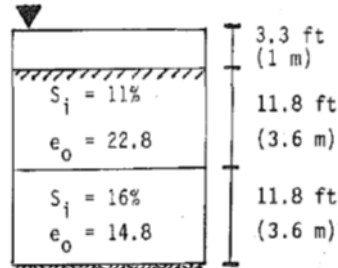


Contour interval= 2.0000E-01
(zero contour omitted)

Grid plot



Layer 1, Activated (Undrained)



Scenario B

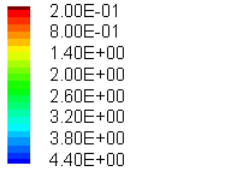
JOB TITLE : Verification: Townsend and McVay (1990), Scenario B

FLAC (Version 8.10)

LEGEND

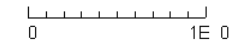
2-Sep-19 15:24
step 96
-1.000E-01 <x< 3.800E+00
-1.000E-01 <y< 3.800E+00

Pore pressure contours

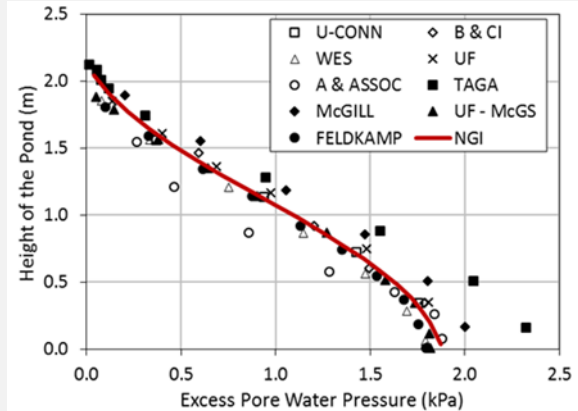
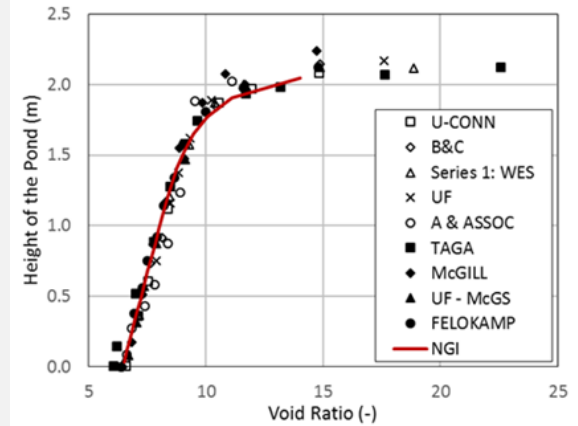
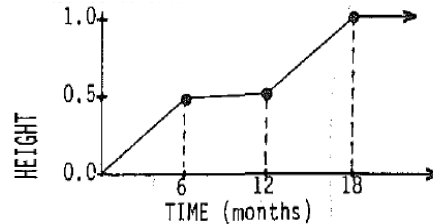
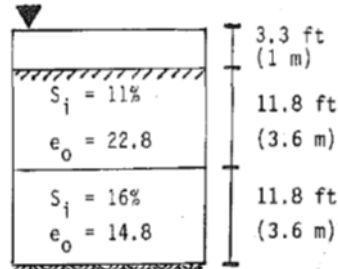


Contour interval= 2.0000E-01
(zero contour omitted)

Grid plot



Layer 1, Activated (Undrained)

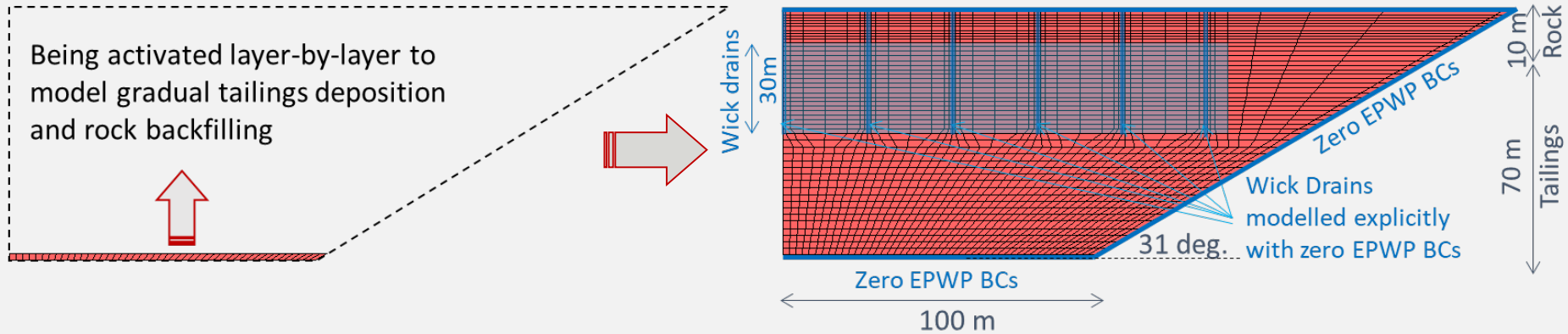


After 1 year consolidation

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Modelling Details



Pre-Designed FLAC Grid of Tailings & Rock Consolidation in a Pit
(Half Cross-Section of the Axisymmetric Model)

Modified from: Amodio et al (2019)

FLAC (Version 8.00)LEGEND

30-Aug-19 22:17

step 0

 $-1.000\text{E}+01 \leq x < 2.500\text{E}+02$ $-1.500\text{E}+02 \leq y < 1.100\text{E}+02$

Pore pressure contours

0.00E+00

4.00E+01

8.00E+01

1.20E+02

1.60E+02

2.00E+02

2.40E+02

2.80E+02

Contour interval= 2.00E+01

friction

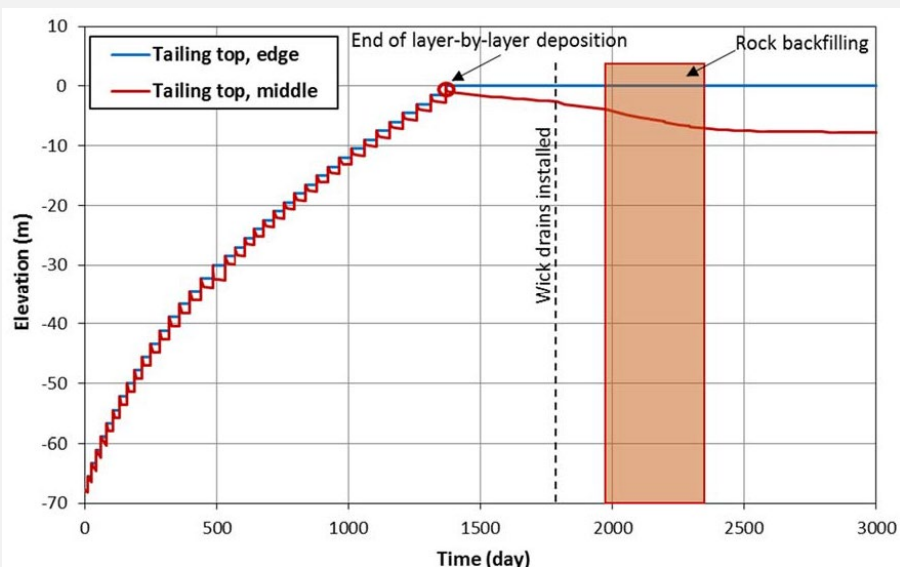
*** All values = 2.50E+01

Boundary plot

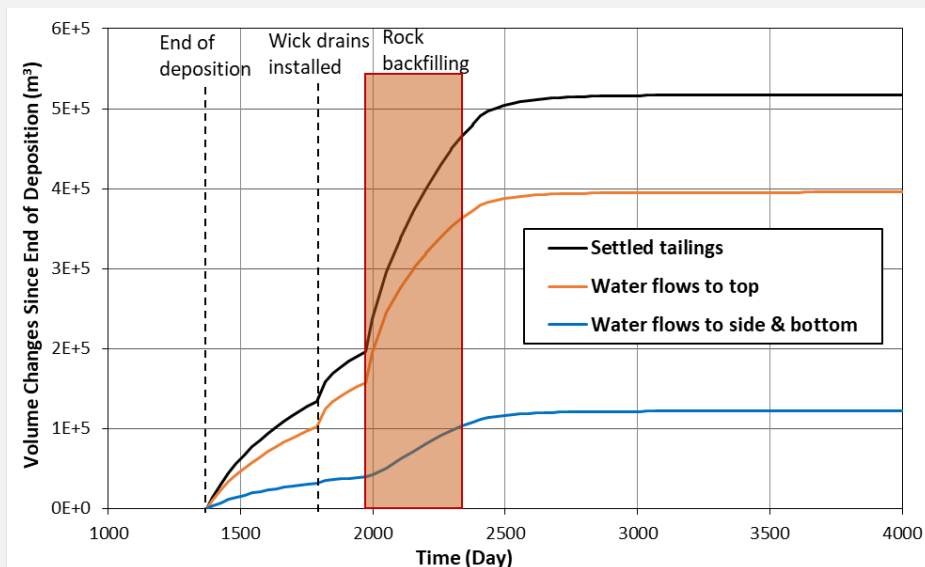
Layer 1, Activated (Undrained)

Example Results

Variation in the elevation of tailings surface during deposition, rock backfilling and consolidation



Tailings consolidation and expression of excess water



Concluding Remarks

- The presented multi-dimensional modelling approach explicitly captures all the key aspects associated with tailings consolidation in a multi-dimensional space.
- Built on FLAC, is reliable and powerful.
- Results have been validated against publications.
- There is also great potential in extending the capability of the modelling approach, such as linking the consolidation to the strength of the tailings and hence include stability calculations within the same framework.

Acknowledgment

I would like to acknowledge the Itasca team in Melbourne (and US) for the continuous support and my NGI's colleagues in Perth and Oslo.

Thanks!
&
Question?





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