Paste 2025 – AB Fourie, A Copeland, V Daigle & C MacRobert (eds)

doi:10.36487/ACG_repo/2555_26

Investigating the cyclic response of layered densified tailings deposits to drying–wetting phases: insights from shaking table tests

Mamadou Fall [a,*], Fahad Alshawmar [b]

[a] *Department of Civil Engineering, University of Ottawa, Canada*

[b] *Department of Civil Engineering, Qassim University, Kingdom of Saudi Arabia*

Abstract

Over recent decades, advances in thickening technology have enabled the adoption of highly densified tailings (HDT) (thickened and paste tailings) disposal as a viable alternative to conventional slurry tailings disposal. However, the geotechnical response and liquefaction potential of HDT subjected to drying and wetting cycles (e.g. heavy rainfall) under cyclic loading is well understood, especially in seismic regions. This study investigates the impact of drying and heavy rainfall on the behaviour and liquefaction susceptibility of layered HDT under cyclic loading, using a shaking table. Heavy rainfall was simulated to replicate extreme events in Quebec, Canada. A flexible laminar shear box equipped with various sensors and instruments (e.g. pore pressure transducers, 5TEs, cable displacement transducers) was used to simulate depositing of thin layers in the field. Results showed that excess porewater pressure (PWP) in HDT (thickened and paste tailings) deposits (initially exposed or not to drying and wetting phases) developed rapidly during shaking. However, the excess PWP ratio was found to be lower than 0.8 in the layered HDT deposits that were initially exposed to drying and wetting phases, indicating they did not liquefy. In contrast, thickened tailings not exposed to drying and wetting phases liquefied, with PWP ratios reaching 1.0. Post-shaking, the layered thickened and paste tailings deposits initially exposed to a drying and wetting phase exhibited greater resistance to liquefaction compared to those that were not, with excess PWP ratios ranging from 0.8 to 0.9. Contraction and dilation responses were seen in the layered thickened and paste tailings deposits (initially exposed to a drying and wetting [heavy rainfall] phase or not) during the shaking. The layered tailings deposits (initially exposed to a drying and wetting phase) had similar horizontal displacement response to the layered tailings deposits that were not initially exposed to a drying and wetting phase.

Keywords: *thickened tailings, paste tailings, earthquake, liquefaction, geotechnical engineering, rainfall*

1 Introduction

The safe disposal of tailings poses significant challenges in seismically active areas. In response, advanced dewatering technologies known as thickened and paste tailings have been introduced and adopted to mitigate the risk of tailings dam failures caused by liquefaction. Unlike traditional tailings slurries, these technologies create dense, viscous mixtures of tailings and water that do not segregate upon deposition (Robinsky et al. 1991; Edraki et al. 2014; Alshawmar & Fall 2021a, 2021b). The solid content of thickened and paste tailings typically ranges from 50–70% and 70–85%, respectively (Bussière 2007). After being transported through pipelines, these tailings are placed in thin layers to create a stable beach slope of 2–7% (Robinsky 1999; Theriault et al. 2003; Williams et al. 2008). Adopting thickened and paste tailings technologies offers various advantages, such as water and reagent recovery, energy savings, increased tailings density in storage facilities, a reduced environmental footprint, suitability for mine backfilling, and a lower risk of acid rock drainage and dam failure (Jones & Boger 2012; Aldhafeeri & Fall 2017). With lower

* Corresponding author. Email address: mfall@uottawa.ca

water content and higher solid density than traditional tailings impoundments, thickened and paste tailings may be more resilient against liquefaction.

Despite extensive laboratory studies on the seismic and liquefaction responses of conventional and highly dense tailings (e.g. Wijewickreme et al. 2005; Geremew & Yanful 2012; Daliri 2013; Antonaki et al. 2019), research on the impact of heavy rainfall (following drying periods) on the cyclic liquefaction potential of layered, highly densified tailings (such as thickened and paste tailings) under shaking table testing conditions is limited. Therefore, it is crucial for mining and geotechnical engineers to understand the cyclic behaviour and liquefaction susceptibility of these tailings following heavy rainfall, particularly in regions prone to both intense rainfall and strong seismic activity.

This study aims to evaluate the effects of heavy rainfall on the behaviour and liquefaction potential of layered thickened and paste tailings under cyclic loading using shaking table tests. Heavy rainfall was simulated to replicate the extreme event experienced in Petit Saguenay, Quebec, Canada, on 19 July 1996. A flexible laminar shear box (FLSB) mounted on a shaking table and equipped with various sensors (e.g. pore pressure transducers, 5TEs, and cable displacement transducers) was used to recreate the layering process in the field.

2 Materials and methodology

2.1 Materials preparation for thickened and paste tailings

Municipal water (MW) and medium-grained tailings were used to prepare the thickened tailings (TT) and paste tailings (PT) for testing. Using MW instead of process or mine water reduces uncertainties and improves result reproducibility. Chemical substances in process or mine water can precipitate in PT or TT materials, potentially altering their seismic behaviour and impacting result interpretation. Tables 1 and 2 present the primary physical properties and mineral composition (as determined through X-ray diffraction analysis) of the tailings used. Following ASTM D4318-17e1 (ASTM International 2017), Atterberg limits testing confirmed that the tailings are non-plastic, classifiable as sandy silts of low plasticity within the ML group of the Unified Soil Classification System (USCS). The TT and PT specimens were created by blending MW with medium-grained tailings, ensuring that TT and PT samples were prepared separately. To achieve homogeneity, specimens were mixed for 10 minutes using an electric cement mixer. It was essential to prepare separate TT and PP samples to ensure reliable results. Adding water to a PT sample to create TT can cause uneven water distribution, saturation, or air entrapment, introducing inconsistencies and potentially leading to inaccurate results. A Wykeham Farrance vane shear apparatus assessed the workability and flowability of these mixtures. Results indicated that the TT and PT specimens had yield stresses of approximately 63 Pa and 139 Pa, respectively, aligning with ranges reported in prior studies (e.g. Sofrá 2017; Li et al. 2002; Crowder et al. 2002). These yield stress values correspond to solid contents of 70% for TT and 79% for PT.

Table 1 Physical properties of the tailings used versus. sand

	Physical properties						
	G_s	D_{10} (µm)	D_{30} (µm)	D_{50} (µm)	D_{60} (µm)	C_u	C_c
Tailings used	2.8	2.0	10.0	24.5	32.5	–	–
Ottawa sand	2.7	700.0	740.0	880.0	1,000.0	1.4	0.8

Notes: G_s: specific gravity; C_u: coefficient of uniformity; and C_c: coefficient of curvature

Table 2 Mineralogical composition of the tailings used

Mineral	Quartz	Albite	Dolomite	Calcite	Chlorite	Magnetite	Pyrite	Talc	Pyrrhotite	Spinel
Content (wt.%)	91	3.3	1.5	0.4	1.6	0.2	0.1	0.7	0.2	0.2

2.2 Physical model, experimental setup, and instrumentation

The experiments were conducted using a shaking table at the University of Ottawa, Canada (Figure 1a). This setup includes a single-degree-of-freedom structure with an aluminium platform moved horizontally by a hydraulic actuator (Model 244). A FLSB, designed by Alainachi & Fall (2017, 2022) and built at the University of Ottawa (Figure 1b), was used to assess the behaviour of layered TT and PT under one-dimensional cyclic shaking. This FLSB, comprising 22 laminae of 750 × 750 mm with a 2 mm vertical gap between each lamina, is constructed from aluminium alloy and independently supported by linear bearings. Each lamina is guided by stainless-steel rods to restrict movement to one axis, while the total mass is transferred to an external frame to avoid inertia effects. This box was placed on the 1,000 × 1,000 mm (L × W) shaking table, as illustrated in Figure 1b.

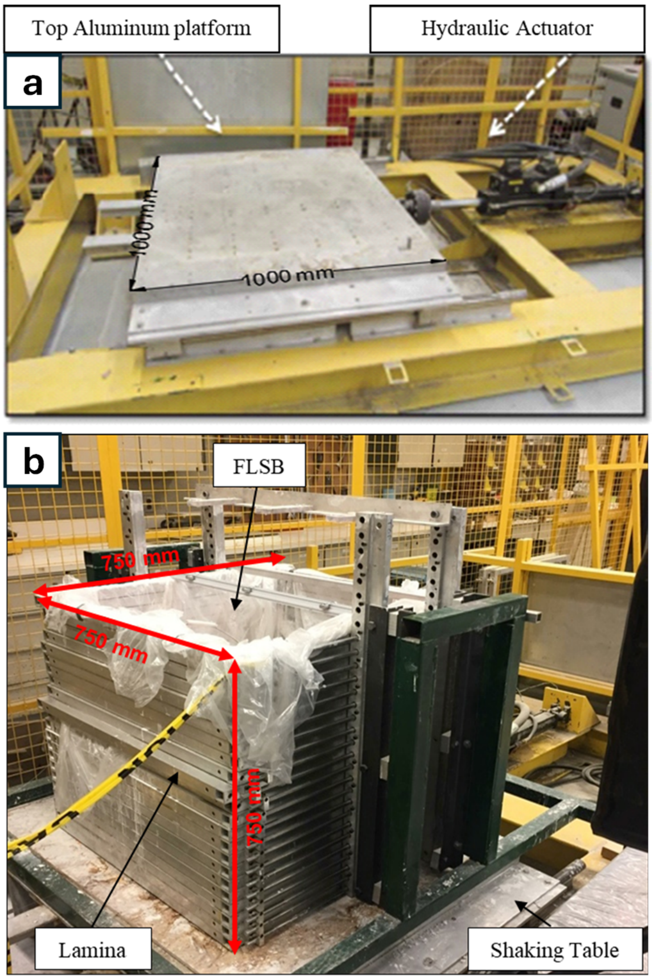


Figure 1 Photographs of (a) the shaking table and (b) the flexible laminar shear box (FLSB) used in this study

A 5.6% slope, as reported for certain TT and PT deposits (Theriault et al. 2003), was simulated by layering coarse-grained sand at the base of the FLSB (Figure 2). To contain both the coarse-grained sand and tailings materials, the FLSB was lined with a thin, flexible plastic bag (Figure 1b). The sloped sand drainage layer was placed on top of the liner, followed by a geotextile to separate the sand from the tailings (Figure 2). This slope falls within typical ranges for TT and PT deposits and plays a role in determining storage volume, facility footprint, and liquefaction susceptibility. The coarse-grained sand used is classified as poorly graded (SP) under the USCS, with its physical characteristics detailed in Table 1. Instrumentation was placed at various depths within the TT and PT layers to monitor responses during testing. Figure 2 displays the FLSB cross-section and sensor placement. Monitoring devices included porewater pressure transducers (P1–P3), 5TE sensors for volumetric water content (5TE1–5TE3), displacement transducers (VD1–VD3 for settlement, HD1–HD3 for horizontal deformation), and accelerometers for measuring the acceleration changes. These sensors were oriented perpendicular to the shaking direction.

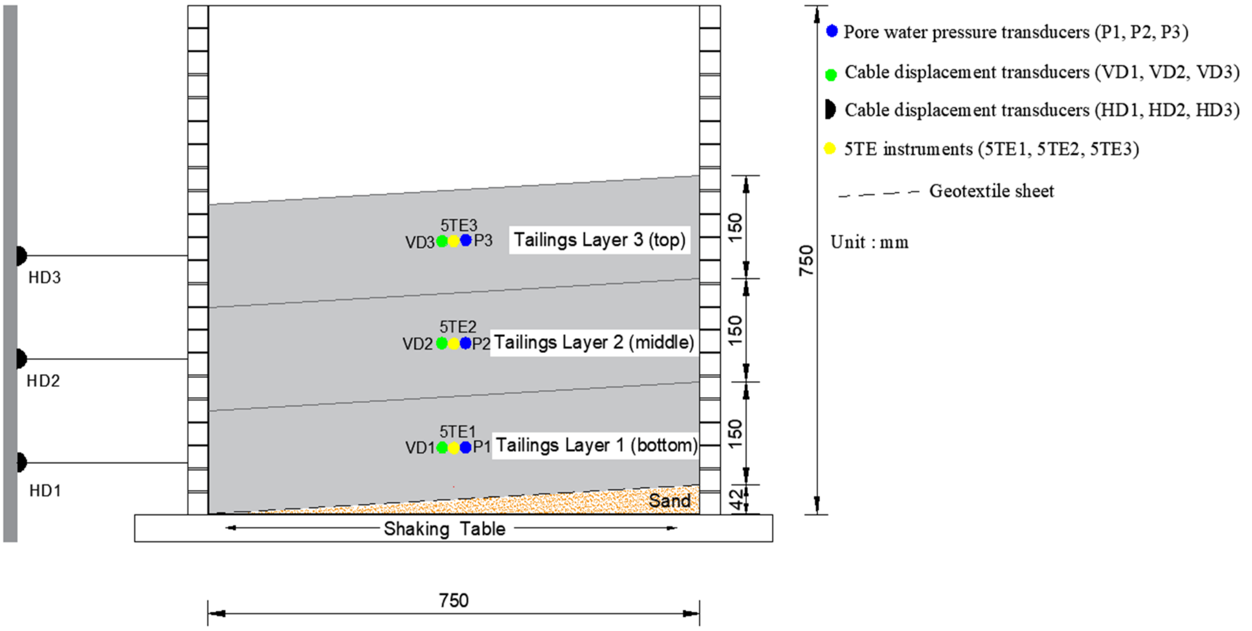


Figure 2 A layer of coarse-grained sand applied to the base of the flexible laminar shear box (FLSB), creating a 5.6% slope, with the instrumented FLSB containing three thin layers of thickened tailings or paste tailings mounted on the shaking table

2.3 Deposition, testing procedures, and rainfall simulation

Field deposition of TT and PT was simulated by layering materials in the FLSB. Each layer was 150 mm thick, with a three-day interval between the first and second layers and a two-day interval between the second and third layers (Figure 3). This sequential layering allowed for desiccation and strength gain before adding subsequent layers, a critical step in stabilising tailings. The laboratory-maintained conditions of 20°C and 57% relative humidity during desiccation. The testing program (Figure 3) included cyclic shaking tests on TT and PT. The first test applied a sinusoidal load at 1 Hz frequency and 0.13 g peak acceleration for up-to 1,800 seconds on the TT deposit. A similar test was conducted on PT deposits. The applied frequency aligns with previous seismic liquefaction studies (Ishihara et al. 1981; James et al. 2003; Pépin et al. 2012) and reflects the Saguenay, earthquake's peak acceleration of 5.9 magnitude (Tuttle et al. 1990). Although actual earthquakes have shorter shaking durations, this extended shaking duration allowed for a more thorough examination of the cyclic behaviour of the TT and PT and enabled a comparative analysis of their responses. Such prolonged shaking is regarded as essential for the future development of a constitutive model aimed at predicting and evaluating the cyclic or seismic behaviour of TT and PT. To study the effect of drying and wetting following deposition, TT and PT deposits were exposed to simulated heavy rainfall after a 10-day drying period to evaluate their response to cyclic loading post-rainfall (Figure 3a). After deposition, fans accelerated the drying process to replicate field-like wind effects. Finally, simulated rainfall was manually applied to saturate the deposits, ensuring approximately 100% saturation was achieved. The degree of water saturation was determined using the classical soil mechanics approach (Liu & Evett 2013) on a small sample extracted from the tailings deposit. The extreme rainfall scenario of 124.8 mm, representing a heavy rainfall event in Petit Saguenay, Quebec, on 19 July 1996 (Government of Canada 2018), was simulated over a five-hour period, applying a runoff-adjusted volume of 62.4 mm. Shaking began one day post-rainfall, continuing until excess pore pressure dissipated. Control tests (Figure 3b) were also conducted on both TT and PT layers without drying or rainfall.

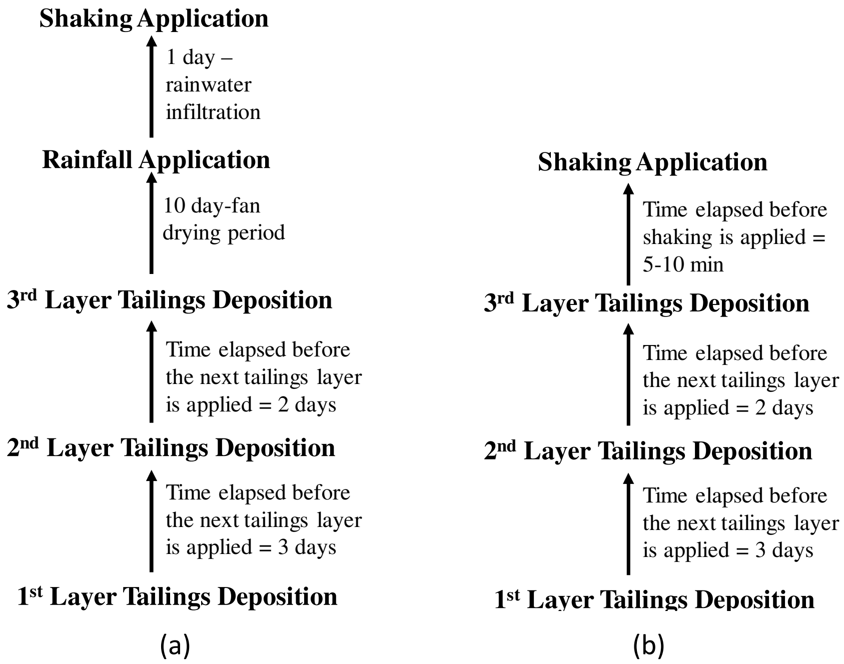


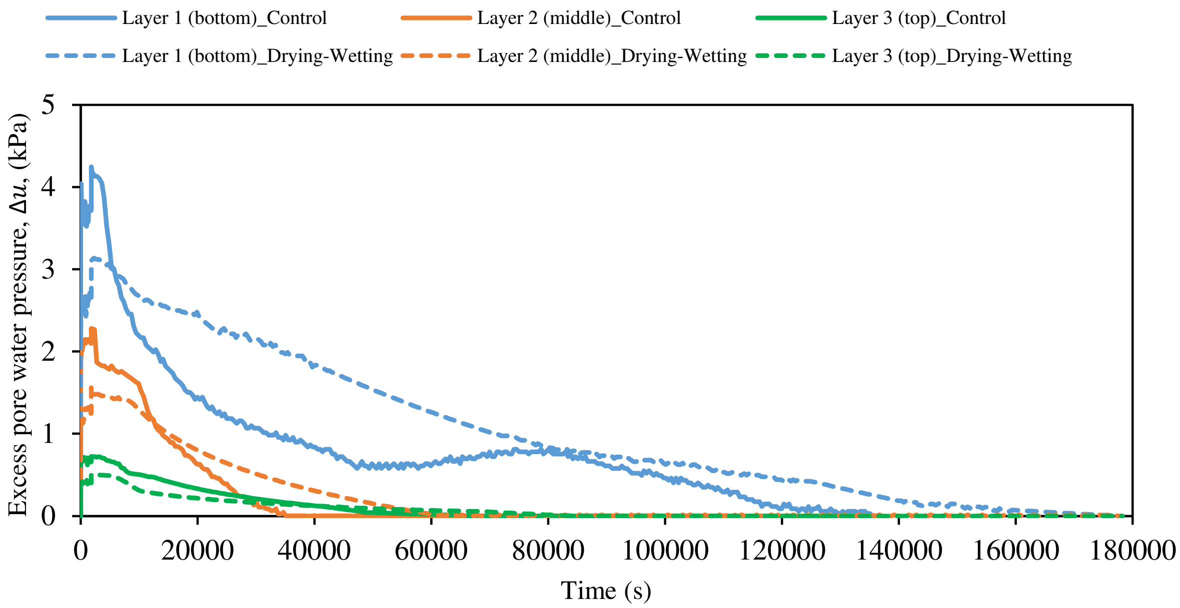
Figure 3 Flow chart of the shaking testing program: (a) analysis of the wetting–drying cycle effects; and (b) control test setup

3 Results and discussion

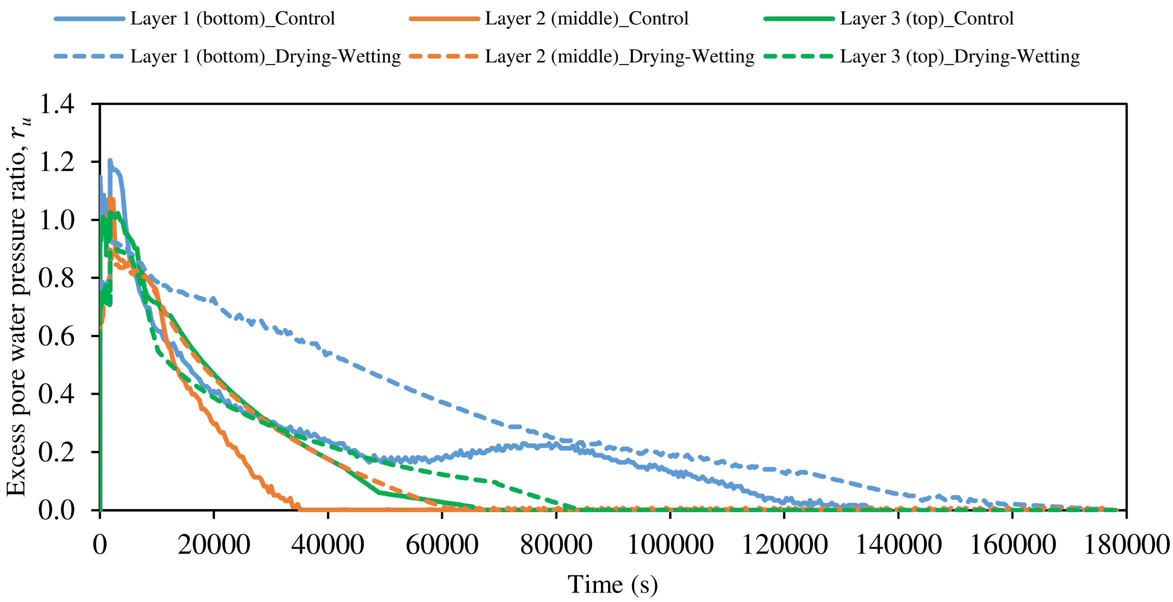
3.1 Porewater pressure response and liquefaction analysis

Various criteria, such as excess pore pressure, strain/deformation, energy, and strength-based criteria, have been used to assess liquefaction potential in natural and human-made soils. Each has its strengths and limitations (Wu et al. 2004). This study evaluates liquefaction potential in TT and PT using excess pore pressure criteria, commonly applied in shaking table studies (e.g. Pépin et al. 2012; Alainachi & Fall 2022; Wang et al. 2020). The excess porewater pressure ratio (r_u), defined as the ratio between excess porewater pressure (Δu) and initial vertical effective stress (σ'_{vo}) (i.e. r_u = $\Delta u/\sigma'_{vo}$), indicates liquefaction when r_u = 1, although liquefaction may also occur at r_u values as low as 0.8 under certain conditions (e.g. Serafini & Perlea 2010). Denser soils have larger shear stress ratios and lower r_u at the onset of liquefaction (Wu et al. 2004).

Figures 4a and 4b show the time evolution of excess porewater pressure and the corresponding r_u, respectively, at the mid-depth of each TT layer during and after shaking for samples initially exposed to a drying and wetting cycle (TT-DW) and those without (TT-NoDW, control). Similarly, Figures 5a and 5b present the data for PT deposits. The onset of shaking led to a rapid increase in excess pore pressure, which stabilised at a peak level until the shaking ceased. This increase is attributed to the contraction of tailings under load, evident from vertical displacement data (Figure 8), suggesting a response that includes both contraction and dilation at low effective stress (Pépin et al. 2012). The peak excess porewater pressures in TT-DW and PT-DW are between 0.4–2.7 kPa and 0.3–2.4 kPa, respectively, while TT-NoDW and PT-NoDW reach higher values, up to 4.0 kPa and 3.2 kPa (Figures 6a and 8a). This indicates that tailings initially exposed to a drying and wetting cycle exhibit lower peak values of excess porewater pressure compared to those that were not. This reduction could result from structural or compositional changes in the tailings exposed to the cycle, leading to increased strength and density. Liu et al. (2015) observed a similar phenomenon, reporting that the cyclic shear strength of silty clay improves following drying and wetting cycles as soil particles are drawn closer together, altering the soil's microstructure. In all tests, the bottom layers of tailings reached peak excess porewater pressure first, followed sequentially by the middle and top layers. This order is likely influenced by water flow from upper to lower layers due to the sand drainage layer at the base, as evidenced in the results of the volumetric water content of PT-DW (Figure 6). This suggest that the porewater pressure in the bottom layer is influenced both by the pressure generated within the layer itself and by the inflow of porewater from the layer above. Pore pressure redistribution during shaking corroborates previous findings on layered soils under seismic conditions (e.g. Naesgaard & Byrne 2007).



(a)



(b)

Figure 4 Excess porewater pressure with time at mid-depth of each layer of thickened tailings (TT) deposit during and after shaking: (a) Measured excess porewater pressure (Δu); and (b) Excess porewater pressure ratio (r_u) (Note: TT-DW [drying–wetting] and TT-NoDW [control])

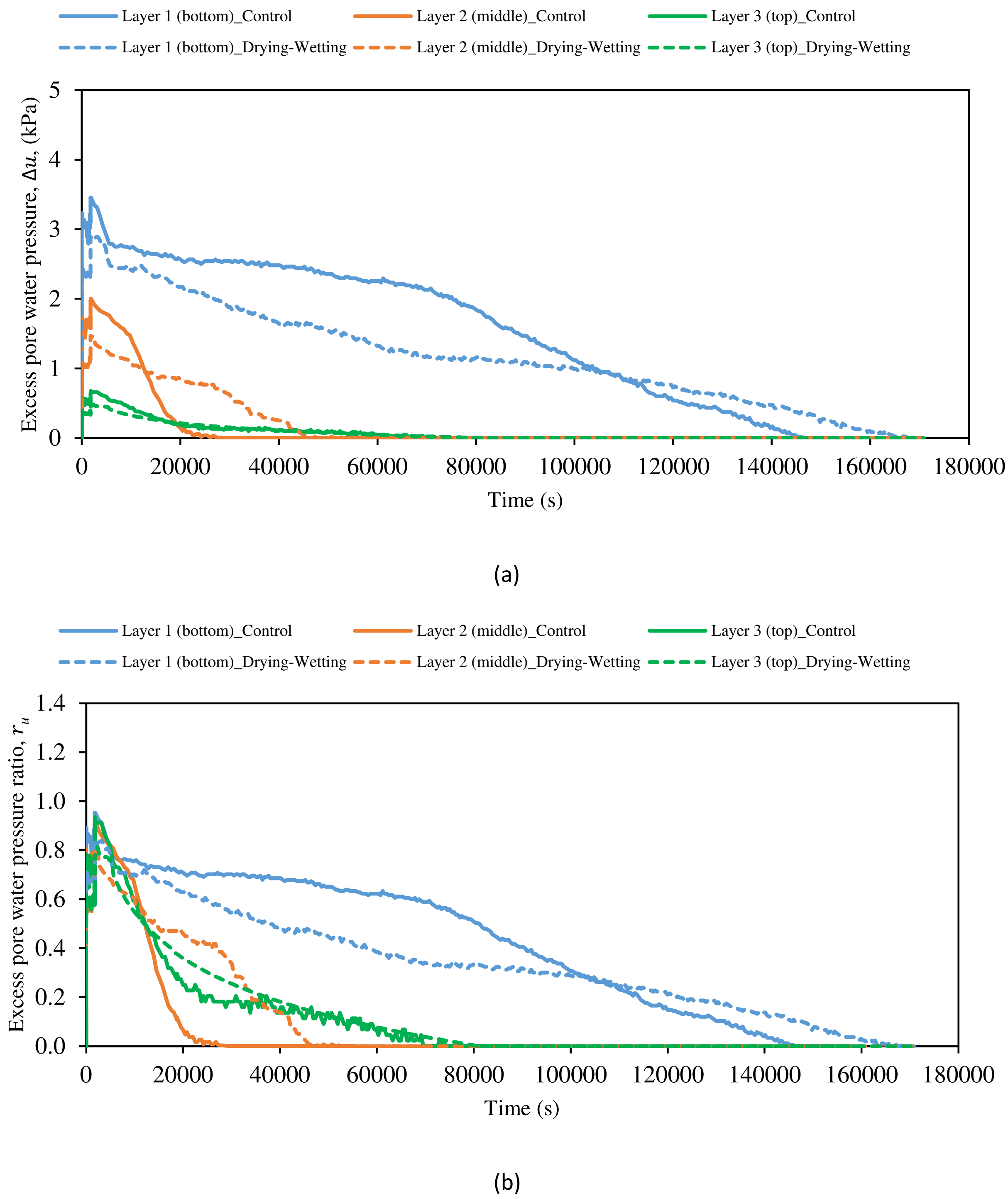


Figure 5 Excess porewater pressure with time at mid-depth of each layer of paste tailings (PT) deposit during and after shaking:)a) Measured excess porewater pressure (Δu); and (b) Excess porewater pressure ratio (r_u) (Note: PT-DW [drying–wetting] and PT-NoDW [control])

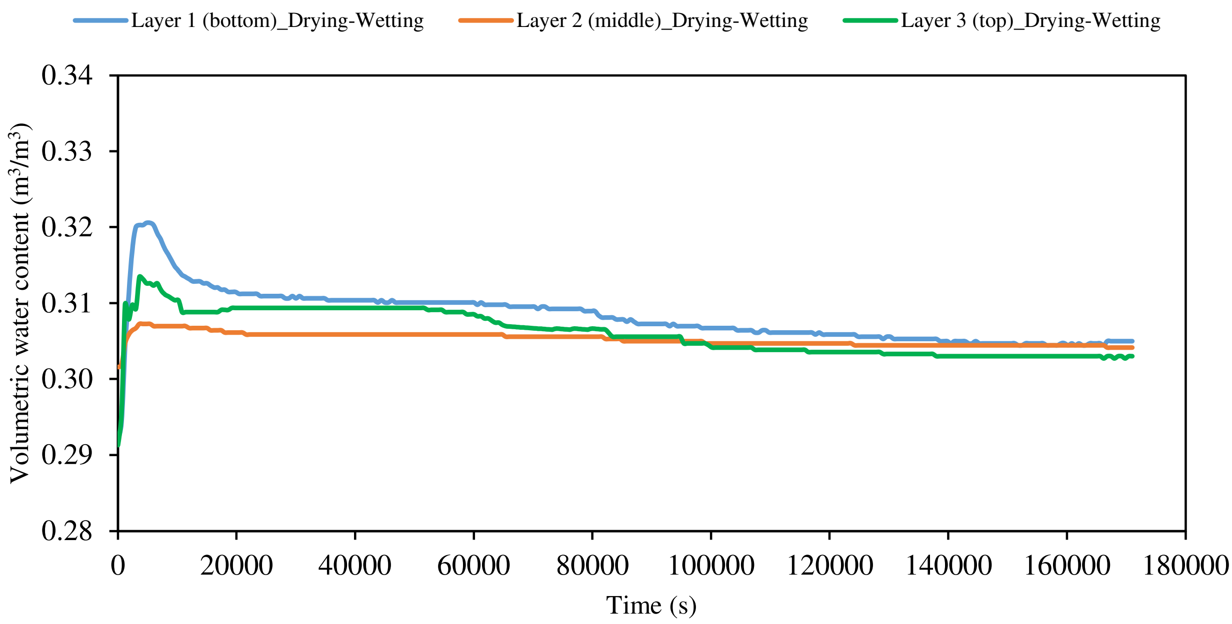
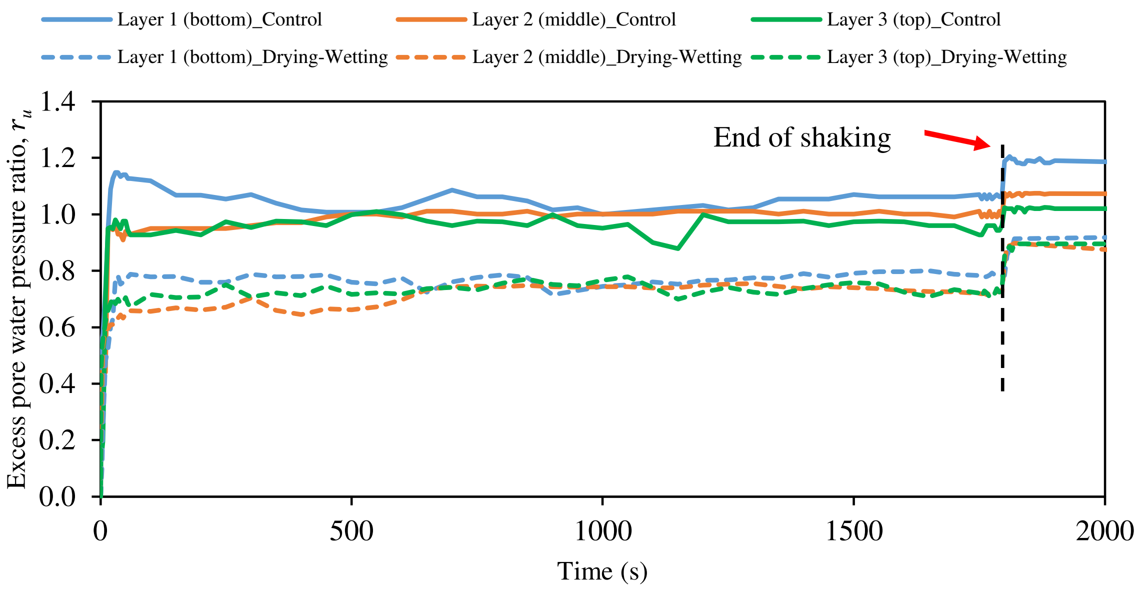
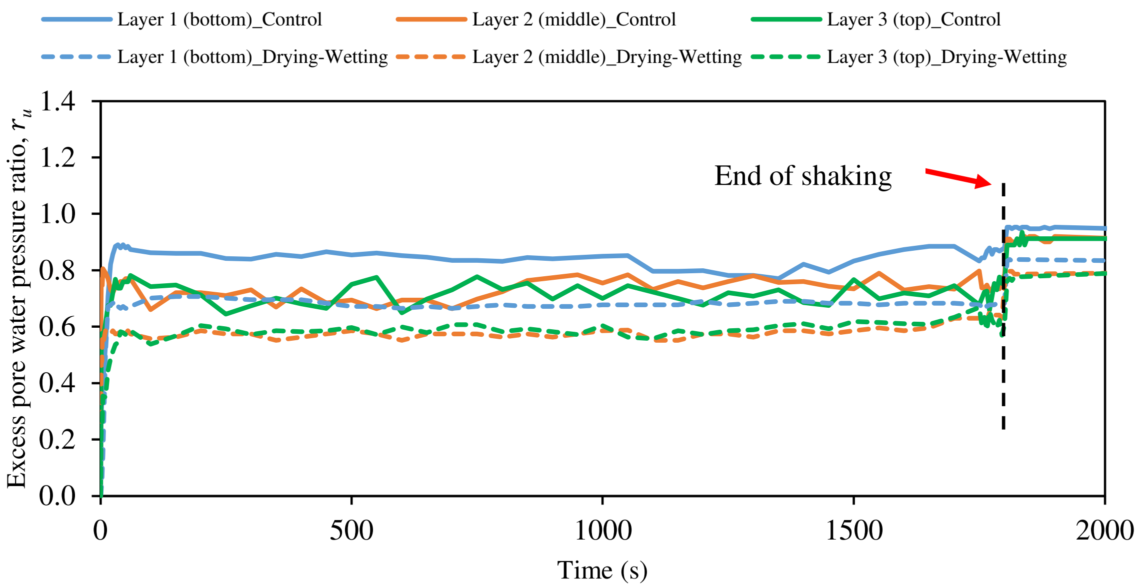


Figure 6 Volumetric water content with time at mid-depth of each layer of paste tailings deposit during and after shaking (Note: PT-DW [drying–wetting])

For TT-DW and PT-DW, r_u reached values between 0.7–0.8 (Figure 7a) and 0.6–0.7 (Figure 7b), respectively, during shaking. In contrast, TT-NoDW and PT-NoDW attained values around 1 or higher, indicating a greater susceptibility to liquefaction in samples without pre-drying cycles. This finding highlights that the drying phase of the TT and PT deposits before the wetting phase (heavy rainfall) can enhance the liquefaction resistance of the TT and PT deposits. In this study, liquefaction is considered to be triggered when $r_u \geq 0.9$. This means that TT-DW, PT-DW and PT-NoDW (control test) resist liquefaction during the long shaking period. After shaking, a sudden increase in excess porewater pressure occurred across all layers of TT and PT deposits, with r_u values reaching 0.8–0.9 in TT-DW and PT-DW, and close to unity in TT-NoDW and PT-NoDW, indicating that TT-DW and PT-DW are resistant to post-shaking liquefaction while TT-NoDW (control test) and PT-NoDW (control test) are susceptible to post-shaking liquefaction. This observation highlights the importance of subjecting HDT to a pre-drying period to enhance stability in seismic zones. Following this initial rise, pore pressure gradually dissipated back to hydrostatic conditions, usually within 9–49 hours (Figures 4 and 5), depending on depth and layer. Longer dissipation times in deeper layers may result from the slower porewater movement through low hydraulic conductivity tailings, as compared to sandy soils (Robinsky et al. 1991; Bussière 2007).



(a)

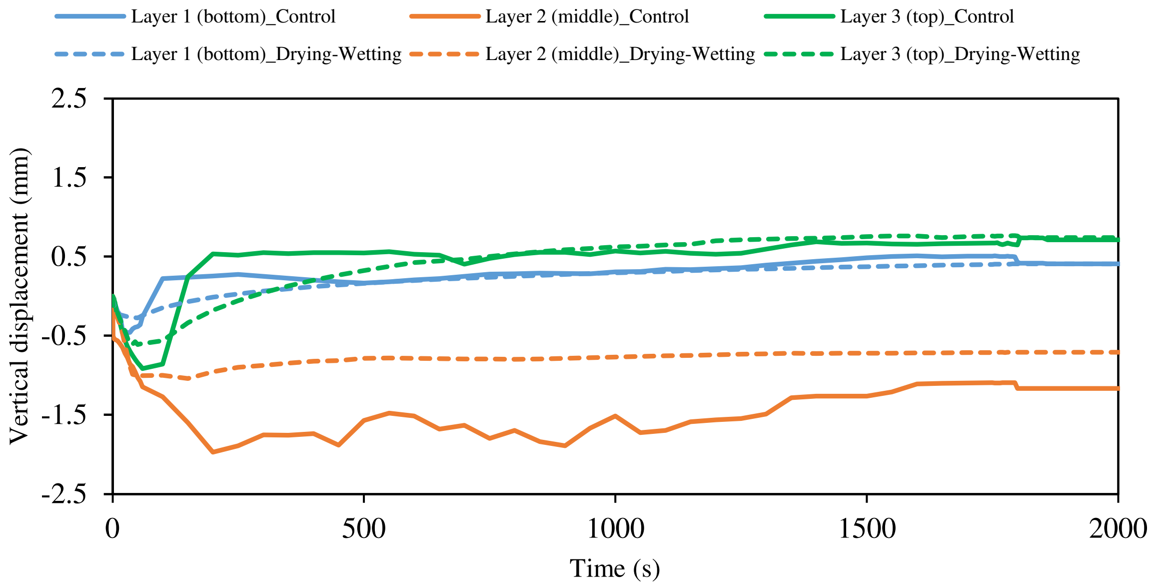


(b)

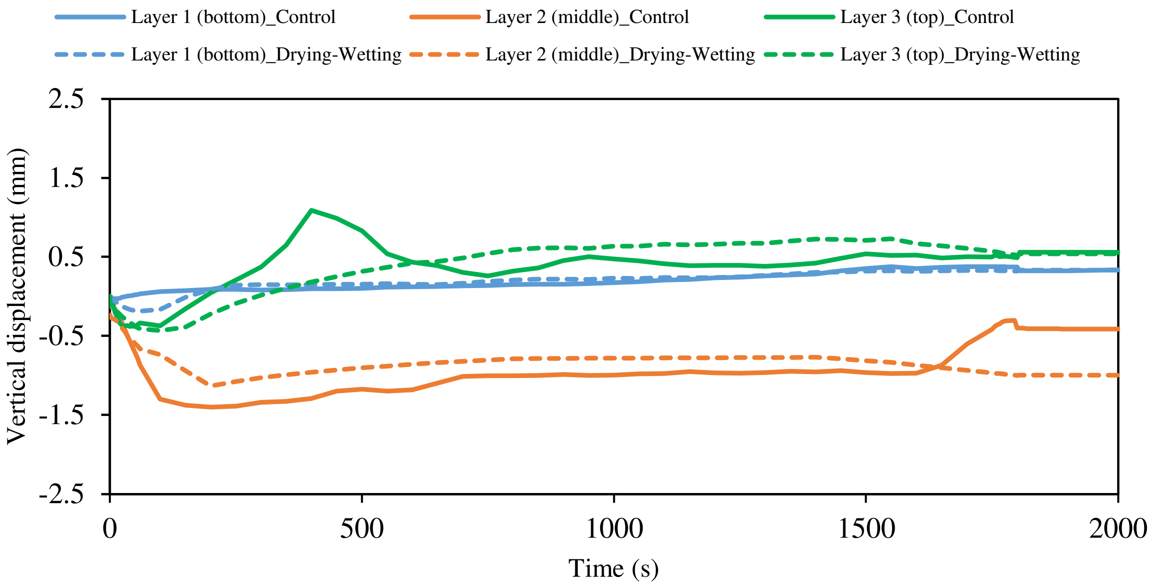
Figure 7 Excess porewater pressure ratio (r_u) with time at mid-depth of each layer of HDT deposit during shaking: (a) thickened tailings; and (b) paste tailings (Note: PT-DW [drying–wetting] and PT-NoDW [control])

3.2 Vertical and horizontal displacement responses

Vertical displacement measurements (Figure 8) reveal contraction and dilation patterns in TT and PT layers during shaking. Initially, all tailings layers displayed settlement due to the contraction induced by the downward movement of the installed plates. TT-DW and PT-DW layers exhibited less settlement (0.29–1.05 mm and 0.20–1.10 mm, respectively) than TT-NoDW and PT-NoDW, which suggests that pre-drying and wetting cycles reduce the extent of settlement. This difference may arise from increased particle cohesion and density in pre-dried samples. Dilation occurred following contraction, with smaller displacements in the bottom layers possibly due to upward water movement from lower sections. The horizontal displacement measurement data revealed a consistent movement pattern across both TT and PT deposits, with maximum horizontal displacements of approximately 8.4–8.8 cm for TT-DW and PT-DW samples, while control samples showed similar but slightly lower values. This similar lateral response at all depths, irrespective of initial drying cycles, aligns with visual observations of FLSB movement, suggesting that lateral deformation characteristics remain relatively uniform across treated and untreated tailings. However, the slightly greater displacement in TT-DW and PT-DW samples might reflect structural changes due to the drying and wetting cycle.



(a)



(b)

Figure 8 Vertical displacement with time at mid-depth of each layer of HDT deposit during shaking: (a) thickened tailings (TT); and (b) paste tailings (PT) (Note: TT-DW [drying–wetting], TT-NoDW [control], PT-DW [drying–wetting] and PT-NoDW [control])

4 Summary and conclusion

In this study, the impact of a drying–wetting cycle on the behaviour and cyclic loading-induced liquefaction potential of TT and PT deposit layers is examined through a series of shaking table tests. The following conclusions were drawn:

- Shaking induces water flow and pressure redistribution within the TT and PT layers, which strongly influences their responses, including excess porewater pressure, liquefaction potential, and vertical displacement.
- Excess porewater pressure at the mid-depth of each TT and PT layer develops immediately and reaches its peak during shaking. However, despite heavy rainfall conditions, TT-DW (TT exposed to drying–wetting) and PT-DW specimens did not liquefy during shaking (ru ≤ 0.80). Similarly, the PT-NoDW (control) specimen showed no liquefaction under cyclic loading (ru ≤ 0.85), whereas the TT-NoDW (control: not exposed to drying–wetting) specimen did liquefy. This pressure increase is primarily due to the contraction of these tailing deposits, with porewater inflow into the top and bottom layers further contributing to excess pore pressure development.
- TT-DW and PT-DW specimens demonstrated resistance to post-shaking liquefaction, whereas TT-NoDW and PT-NoDW (control) specimens were susceptible to liquefaction after shaking.
- During shaking, TT and PT layers initially undergo contraction (or settlement) for a brief period before dilating. After shaking ceases, there are no significant changes in displacement across all tailing deposit layers (TT-DW, TT-NoDW [control], PT-DW, and PT-NoDW [control]). In general, tailing deposits exposed to an initial drying–wetting cycle exhibit similar horizontal displacement patterns to those that were not.

This experimental study enhances understanding of the behaviour and liquefaction potential of TT and PT layers under cyclic loading and the influence of drying and wetting cycles. To further this understanding, future research should explore additional factors, such as varying loading frequencies, different peak horizontal accelerations, extended drying (desiccation) durations, diverse tailing layer thicknesses, variations in beach slopes, and differing rainfall volumes, to comprehensively assess rainfall's effects on the geotechnical and liquefaction responses of TT and PT layers under cyclic loading.

References

Alainachi, I, Fall, M & Majeed, M 2022, 'Behaviour of backfill undergoing cementation under cyclic loading', *Geotechnical and Geological Engineering,* vol. 40, pp. 4735–4759.

Aldhafeeri, Z & Fall, M 2017, 'Sulphate induced changes in the reactivity of cemented tailings backfill', *International Journal of Mineral Processing*, vol. 166, pp. 13–23

Alshawmar, F & Fall, M 2021a, 'Geotechnical behaviour of layered paste tailings in shaking table testing', *International Journal of Mining, Reclamation and Environment*, vol 36, no 3, pp. 174–195.

Alshawmar, F & Fall, M 2021b, 'Dynamic response of thickened tailings in shaking table testing', *International Journal of GeoEngineering*, vol. 12.

Antonaki, N, Abdoun, T & Sasanakul, I 2019, 'Centrifuge tests on liquefaction potential and slope stability of mine tailings', *International Journal of Physical Modelling in Geotechnics*, vol. 19, no. 2, pp. 104–114.

ASTM International 2017, *Standard Test Methods for Liquid Limit, Plastic Limit, and Plasticity Index of Soils (ASTM D4318-17e1)*, West Conshohocken.

Bussière, B 2007, 'Colloquium 2004: hydrogeotechnical properties of hard rock tailings from metal mines and emerging geoenvironmental disposal approaches', *Canadian Geotechnical Journal*, vol. 44, no 9, pp. 1019–1052.

Crowder, JJ, Grabinsky, MWF & Klein, KA 2002, 'Laboratory characterization of tailings paste for surface disposal', *Proceedings of the 55th Canadian geotechnical conference*, The Canadian Geotechnical Society, Vancouver.

Daliri, F 2013, *The Influence of Desiccation and Stress History on Monotonic and Cyclic Shear Response of Thickened Gold Tailings*, PhD thesis, Carleton University, Ottawa.

Edraki, M, Baumgartl, T, Manlapig, E, Bradshaw, D, Franks, DM & Moran, CJ 2014, 'Designing mine tailings for better environmental, social and economic outcomes: a review of alternative approaches', *Journal of Cleaner Production*, vol. 84, pp. 411–420.

Geremew, AM & Yanful, EK 2012, 'Laboratory investigation of the resistance of tailings and natural sediments to cyclic loading' *Geotechnical Geological Engineering*, vol. 30, no. 2, pp. 431–447.

Government of Canada 2018, *Canadian Climate Normals 1981–2010 Station Data*, Environment and Natural Resources, https://climate.weather.gc.ca/climate_normals/results_1981_2010_e.html?stnID=5720&autofwd=1

Ishihara, K, Yasuda, S & Yokota, K 1981, 'Cyclic strength of undisturbed mine tailings', *Proceedings of the First International Conference on Recent Advances in Geotechnical Earthquake Engineering and Soil Dynamics*, University of Missouri-Rolla, Rolla, vol. 1, pp. 53–58.

James, M, Jolette, D, Aubertin, M & Bussière, B 2003, 'An experimental set-up to investigate tailings liquefaction and control measures', *Proceedings of the International Symposium on Major Challenges in Tailings Dams (ICOLD*), vol. 15, pp. 153–164, Montreal.

Jones, H & Boger, DV 2012, 'Sustainability and waste management in the resource industries', *Industrial and Engineering Chemistry Research*, vol. 51, no. 30, pp. 10057–10065.

Li, M, Bernier, L & Boucher, J-F 2002, 'Rheology of mineral pastes and its implications on underground pipeline delivery', *Proceedings of Symposium 2002 on Environment and Mines*, Canadian Institute of Mining, Metallurgy, and Petroleum, Westmount.

Liu, C & Evett, J, 2013, *Soils and Foundations*, 8th edn, Pearson, Upper Saddle River.

Liu, W, Tang, X, Yang, Q & Li, W 2015, 'Influence of drying/wetting cycles on the mechanical cyclic behaviours of silty clay', *European Journal of Environmental and Civil Engineering*, vol. 19, no. 7, pp. 867–883.

Naesgaard, E & Byrne, PM 2007, 'Flow liquefaction simulation using a combined effective stress–total stress model', *Proceedings of the 60th Canadian Geotechnical Conference*, Ottawa, pp. 21–24.

Pépin, N, Aubertin, M, James, M & Leclerc, M 2012, 'Seismic simulator testing to investigate the cyclic behaviour of tailings in an instrumented rigid box,' *Geotechnical Testing Journal*, vol. 35, no. 3, pp. 469–479.

Robinsky, EI 1999, *Thickened Tailings Disposal in the Mining Industry*, E.I. Robinsky Associates, Toronto.

Robinsky, E, Barbour, SL, Wilson, GW, Bordin, D & Fredlund, DG 1991, 'Thickened sloped tailings disposal-an evaluation of seepage and abatement of acid drainage', *Proceedings of the Second International Conference on the Abatement of Acidic Drainage*, Montreal, pp. 529–549.

Serafini, DC & Perlea, V 2010, 'Comparison of liquefaction triggering analysis approaches for an embankment dam and foundation', *Proceedings of the 5th International Conference on Recent Advances in Geotechnical Earthquake Engineering and Soil Dynamics*, Missouri University of Science and Technology, Rolla.

Sofrá, F 2017, 'Rheological properties of fresh cemented paste tailings', in E Yilmaz & M Fall (eds), *Paste Tailings Management*, Springer, Cham, pp. 33–57.

Theriault, J, Froastiak, J & Welch, D , 2003, 'Surface disposal of past tailings at the bulyanhulu gold mine, Tanzania', *Proceedings of Sudbury Mining Environment Conference (CD-ROM)*, Centre for Environmental Monitoring, Laurentian University, Sudbury.

Tuttle, M, Law, KT, Seeber, L & Jacob, K 1990, 'Liquefaction and ground failure induced by the 1988 Saguenay, Quebec, earthquake, *Canadian Geotechnical Journal*, vol. 27, no. 5, pp. 580–589.

Wang, J, Salam, S & Xiao, M 2020, 'Evaluation of the effects of shaking history on liquefaction and cone penetration resistance using shake table tests', *Soil Dynamics and Earthquake Engineering*, vol. 131.

Wijewickreme, D, Sanin, MV & Greenaway, GR 2005, 'Cyclic shear response of fine-grained mine tailings', *Canadian Geotechnical Journal*, vol. 42, no. 5, pp. 1408–1421.

Williams, MPA, Seddon, KD & Fitton, TG 2008, 'Surface disposal of paste and thickened tailings — a brief history and current confronting issues', in R Jewell, AB Fourie, P Slatter & A Paterson (eds), *Paste 2008: Proceedings of the Eleventh International Seminar on Paste and Thickened Tailings*, Australian Centre for Geomechanics, Perth, pp. 143–164, https://doi.org/10.36487/ACG_repo/863_14

Wu, J, Kammerer, AM, Riemer, MF, Seed, RB & Pestana, JM 2004, 'Laboratory study of liquefaction triggering criteria', *Proceedings of the 13th World Conference on Earthquake Engineering*, 13WCEE Secretariat, Vancouver.