Assessing Static Liquefaction for Upstream Tailings Dams

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ABSTRACT

Static liquefaction imposes a high risk for many tailings dams as it has contributed to catastrophic failures in recent years that have resulted in a large number of fatalities and extensive environment damage to downstream communities. Static liquefaction due to brittle behaviour of contractive tailings upon liquefaction and sudden failures imposes a serious challenge to tailings dam designers and operators. To make the problem even more complex is the variability in location of these contractive layers due to variability in deposition methods and deposition environment and flow behaviour of tailings slurries.

There is abundant research and investigations into soil liquefaction under cyclic and seismic loadings. Consequently, the current design codes and guidelines provide detailed procedures to address the soil liquefaction for seismic design. On the other hand, static liquefaction is less understood and the current design codes and guidelines do not provide detailed guidance on the approach to address static liquefaction. However, liquefaction is another constitutive behaviour of soils that could be understood in terms of accepted physics and mechanics (Been and Li, 2009). Critical state soil mechanics provides a framework to quantify the soil liquefaction potential under static loading conditions (Jefferies and Been, 2015).

This paper presents a design approach and analytical methods that were used for assessing the potential of static liquefaction and developing the mitigation measures for a tailings dams in Australia. The rigour of the design and analysis approach represented(s) the best practise in the industry to address static liquefaction, which contributed to a robust design with high confidence and certainty. The salient features of our approach to static liquefaction included geotechnical investigation and tailings characterisation, static liquefaction screening assessment, static liquefaction triggering analysis, limit equilibrium analyses and numerical modelling of static liquefaction using the NorSand model, which is the first tailings project in Australia involving numerical modelling of static liquefaction using these methods.

Geotechnical investigation campaigns were undertaken for the site progressively with an objective on identifying the soft tailings and well controlled in situ testing and thin-walled sampling using piston samplers. Advanced soil testing was carried out to determine the critical state lines and stress dilatancy properties of the tailings and stress path testing to determine the brittleness of the materials after ko consolidation. The tailings characterisation indicates that both the sand-like tailings and the clay-like tailings exhibit a brittle behaviour suffering from strain softening at large strains although the slope of the critical state lines were distinctly different. For numerical modelling, extensive model calibration analyses were undertaken to achieve excellent correlation between the measured stress-strain, stress path and excess pore water pressures. The embankment construction, tailings deposition and rise of pore pressures were simulated in numerical modelling using a finite difference package FLAC. The modelling analyses identified the potential liquefiable zones and predicted the excess pore pressures and anticipated shear deformations at different stages of the operation of the facility. The field monitoring and instrumentations were targeted at these locations during construction and operation and trigger levels determined for these instruments. The embankment raise and the required buttress were constructed successfully and the performance met the design expectations.