AUSTRALIAN NATIONAL COMMITTEE

ON LARGE DAMS

GUIDELINES ON TAILINGS DAMS

PLANNING, DESIGN, CONSTRUCTION, OPERATION AND CLOSURE

Addendum

July 2019

IMPORTANT WARNING

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Introduction

ANCOLD published its current Guidelines on Tailings Dams in May 2012. The Guidelines have been widely used both in Australia and internationally.

Since 2012, there have been a number of tragic tailings dam failures which have attracted world-wide attention. This addendum is ANCOLD's initial response to these events and other relevant matters.

Some of the important matters covered in this addendum include reinforcement of the need for robust management practices, updates on earthquake considerations to align with the forthcoming ANCOLD Guidelines for Design of Dams and Appurtenant Structures for Earthquake and additional information on static liquefaction.

In regard to management practices, the need for users of the Tailings Guidelines to also take account relevant aspects of the ANCOLD Guidelines on Dam Safety Management (2003) must be emphasised. ANCOLD considers it essential that these two guidelines be used together by practitioners seeking to manage tailings dam safety.

This addendum is provided free of charge but must only be used in conjunction with the 2012 Guidelines on Tailings Dams and not referred to as a stand-alone document.

ANCOLD is pleased to continue its contributions to the promotion of tailings dam safety. The work has been prepared through a great deal of voluntary work by the Tailings Dam Sub-Committee of ANCOLD, led by Mr David Brett.

As with all ANCOLD guidelines, this guideline is not a design code or standard and has been produced for the guidance of experienced practitioners who are required to apply their own professional skill and judgement in its application. Users must keep abreast of developments in the management and design of tailings dams and take those developments into account when using these guidelines.

The guidelines will again be reviewed when knowledge and practice have developed to a point when an update is required. Accordingly, ANCOLD welcomes comments from users and other interested parties.

Shane McGrath

Chairman of ANCOLD Inc

The following amendments have been made to the 2012 ANCOLD Guidelines (ANCOLD, 2012). These have been introduced into Rev 1 dated July 2019.

Page 1 Section 1.1, Introduction, at the end of the Section add:

"Revision 1, dated July 2019, has added clarifying information to make the Tailings Guideline compatible with current design loadings for earthquake as detailed in the ANCOLD Guidelines for Design of Dams and Appurtenant Structures for Earthquake (ANCOLD, 2019). In addition, following some recent tailings dam failures, changes have been made to indicate good management and accountability practice, aimed at reducing the likelihood of tailings dam failure."

Page 6, Section 1.9 Definitions, replace the definition of Operating Basis Earthquake as follows:

"Operating Basis Earthquake (OBE) -–The OBE is that level of ground motion at the dam site which leads to only minor damage. The dam, appurtenant structures and equipment should remain functional and damage from the occurrence of an earthquake not exceeding the OBE should be easily repairable."

Page 6, Section 1.9 Definitions –replace

"Maximum Design Earthquake (MDE)" with" Safety Evaluation Earthquake (SEE)"

Page 6, Section 1.9 Definitions – replace the definition of Maximum Credible Earthquake (MCE) as follows:

"Maximum Credible Earthquake (MCE) – the MCE is the largest reasonably conceivable earthquake magnitude that is considered possible along a recognised fault or within a geographically defined tectonic province, under the presently known or presumed tectonic framework."

Page 11, 12, Section 2.3.1, Dam Failure Consequence Category, add:

"Dam Failure" before "Consequence Category" in all locations where these words are omitted.

Page 14, add text below Table 2:

"Table 2 can also be used to determine the Environmental Spill Consequence Category, described below. However, it is unlikely that there would be population at risk for this application unless spilled water/tailings was particularly toxic and likely to be ingested by downstream populations."

Page 19, replace Section 2.6:

Due to the complexity of many tailings dams and the range of experience and skill required in their planning, design and operation, it is recommended that dam owners procure independent strategic third party reviews at critical phases of the TSF life-cycle. This independent review could take place during concept and feasibility studies, design, construction, operation and closure.

For High or Extreme Dam Failure Consequence Category Dams a team of specialist reviewers should be considered for Third Party review. This could take the form of an Independent Technical Review Board (ITRB) reporting directly to mine management, involved in periodic site visits, and overview of design and operational aspects.

These reviews are in addition to dam safety reviews referred to in Section 8."

Page 19, add Sections:

“2.7 Management Structure and Accountability

Experience with recent tailings dam failures has highlighted the need to designate direct responsibility for dam safety performance within the mine management structure and the inclusion of an appropriate level of qualification and experience within the management team. ANCOLD Guidelines on Dam Safety Management (2003) provides guidance on developing and maintaining an appropriate dam safety program and the Mining Industry of Canada (MAC) provides useful advice specific to tailings facilities (MAC, 2017). The following positions are recommended as minimum within the MAC Guidelines.

Accountable Executive Officer

A specific board member or senior management person should be allocated responsibility to ensure that management of the tailings dams is being properly addressed in accordance with legislative requirements, site-specific conditions and appropriate technical guidelines. This would include ensuring that staff are properly qualified and trained for their positions.

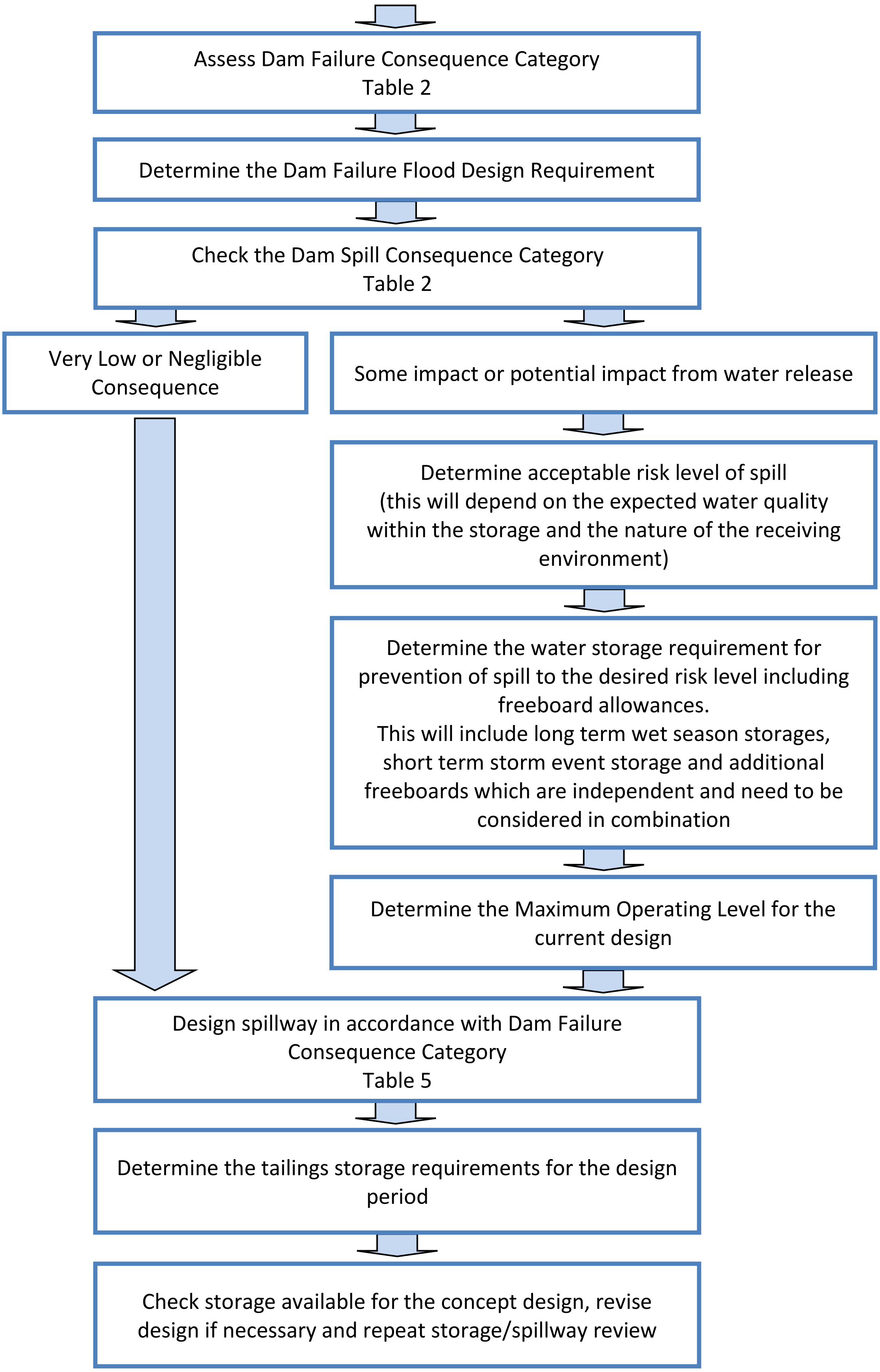
Responsible Site Person

In addition to the accountable management representative, there should be a responsible site-based person assigned to each tailings dam. The Responsible Site Person should have clearly defined responsibility for tailings management and be appropriately qualified and experienced. The Responsible Site Persons duties would include implementation of the tailings management plan, identifying the scope of work and budget requirements for all aspects of tailings management and delegating specific tasks and responsibilities for aspects of tailings management to qualified personnel.

Responsible Technical Person

In addition to the Responsible Site Person, there should be a Responsible Technical Person assigned to each tailings dam This person, named the “Engineer of Record” in some jurisdictions, must be appropriately qualified and experienced in the scale and type of dam involved. The responsible technical person should have overall responsibility to verify that all investigation, design and operation activities are appropriate and properly carried out. This person could be a staff member or external consultant, but the employment structure must allow for continuity of the position and appropriate change management if changes to the position are made. The responsible technical person should have a direct reporting line to senior mine management and the company Board.

Page 33, Section 5, Figure 5 - Flow Sheet for Tailings Dam Spillway and Storage Design, replace Figure 5 with following:



Page 35, Section 5.1.4, Spillways, last line, replace:

"MDE" with "SEE".

Page 43, Section 6.1.3, Loading Conditions, add the following paragraphs after paragraph 2:

"Where tailings dams involve uncompacted materials such as deposited tailings and/or normally consolidated clayey layers in their foundation, which can exhibit contractive behaviour, the drained shear failure mode is likely to over-predict the stability of the dam.

Long-term stability analyses must consider all materials that are contractive and generate pore pressures on shearing. These materials should always be modelled in accordance with the Undrained Strength Analysis (USA) approach as described in Sections 6.1.3.2 and 6.1.4.

The ANCOLD (2012) Guideline includes some discussion of the static liquefaction mechanism. However, owing to recent tailings failures from static liquefaction, it was deemed useful to add additional information to the Guideline specific to static liquefaction.

Add section 6.1.3.3. Static liquefaction

Static liquefaction represents a particularly brittle subset of contractive undrained shearing of loose, near-saturated materials, wherein substantial strength loss occurs following a triggering event, causing a change in stresses within the structure. The shear resistance of the materials subject to static liquefaction reduces rapidly due to the excessive strain-induced pore water pressures. Importantly, the process of static liquefaction is of such brittleness that often little, if any, warning is evident from typically-observed aspects of a TSF behaviour, such as pore water pressures, surface deformation and/or cracking.

Several trigger mechanisms are well documented, such as a rapid change in loading, change in the state of drainage or deformation of the structure. However, the assessment of trigger mechanisms for static liquefaction is very difficult. Accordingly, a conservative approach to stability assessments involving materials susceptible to static liquefaction would be to assume that triggering does occur. The Factor of Safety for static liquefaction should be considered with reference to Table 8 of these guidelines, allowing the static-liquefaction condition to be equivalent to the post-seismic loading condition. For a stability assessment of high consequence dams, it is also considered necessary to assume undrained conditions for contractive materials regardless of whether or not the undrained behaviour is expected.

Current recommended guidance is that if the tailings or any other materials, which may be important for the TSF stability, are brittle and potentially contractive, significant rigour is required in the assessment of the liquefaction susceptibility, stability assessment and the triggering analyses. Such assessment can employ the critical state soil mechanics theory (Jefferies & Been 2015), which express the in situ state of the materials with respect to the yield surface (critical state) using state parameters. The state parameter can be determined from field investigation data (Robertson, 2010) and a combination of field investigation and laboratory data (Jefferies & Been 2015). Design criteria for static liquefaction should follow a similar approaches to that of earthquake liquefaction in terms of factors of safety and deformation as described in Section 6.1.6 of this Guideline.

Due to the high complexity of the assessment procedure, subject matter experts should be engaged for rigorous analysis of TSFs where potentially liquefiable materials play vital roles in the TSF's integrity.

Page 44, Section 6.1.5, Earthquake Considerations, add the following, prior to first paragraph:

“Design of tailings dams for earthquake loadings should be undertaken in compliance with the ANCOLD Guidelines for Design of Dams and Appurtenant Structures for Earthquake (ANCOLD, 2019).

Page 45, Section 6.1.5, Earthquake Considerations, after dot points, delete the sentence:

“Reference may be made to Australian Standard AS 1170.4-1973, however this does not cover the wide range of earthquake probabilities relevant to dam design.”

Page 45, Section 6.1.5, Earthquake Considerations, replace reference:

“MDE” with “SEE”.

Page 45, Section 6.1.5, Earthquake Considerations, replace Table 7 with the following:

“Table 7 Recommended seismic design ground motions. Adapted from Table 2.1 ANCOLD 2019

Dam Failure Consequence Category	**Operational Phase**	
	Operating Basis Earthquake (OBE)(1)	**Safety Evaluation Earthquake (SEE)(2,8)**
Extreme	Commonly 1 in 475 AEP up to 1 in 1,000 AEP	The greater of: Ground motion from the MCE on known active faults (3) or Probabilistic ground motion Extreme: 1 in 10,000 AEP(4)
High A, B and C	Commonly 1 in 475 AEP up to 1 in 1,000 AEP	Probabilistic ground motion(5,6,7): High A: 1 in 10,000 AEP High B: 1 in 5,000 AEP High C: 1 in 2,000 AEP
Significant	Commonly 1 in 475 AEP	Probabilistic ground motion(5,6): 1 in 1,000 AEP
Low	Commonly 1 in 475 AEP	Probabilistic ground motion(5,6): 1 in 1,000 AEP

Notes

(1) To be determined by the Owner and other Stakeholders in consultation with the Dam Design Consultant and/or Engineer of Record.

(2) The design of the dam should be such that there will be a low likelihood of the dam failing given the SEE.

(3) Active faults are as defined in ANCOLD, 2019

(4) 85th fractile. This is required so that the design is more likely to have a sufficiently low likelihood of failure given the SEE than if the median loading was used.

(5) Median, 50th fractile.

(6) For High B, High C, Significant, and Low Dam Failure Consequence Category dams, if the structure is susceptible to liquefaction or has components that will fail at ground motions only a little greater than those presented in Table 2.1, check the design for the critical ground motion and assess the adequacy of the design using risk assessment methods.

(7) Adoption of these SEE criteria for High B and High C Dam Failure Consequence Category dams may not provide an acceptable level of risk in accordance with the Loss of Life criteria contained in

ANCOLD (2003), or where catastrophic environmental impact is likely. It is therefore recommended that some level of risk assessment should be undertaken in these cases before adopting the AEP stated in the table. If it cannot be demonstrated that an acceptable level of risk would be achieved, a higher earthquake loading should be adopted.
(8) These Guidelines have been developed specifically for Australia, which is a region of relatively low seismic activity, making estimation of a realistic MCE difficult. Accordingly, the use of probabilistic methods to estimate the SEE is preferred. However, if using this Guideline in other regions, the choice of an appropriate SEE needs to take into account the regional seismicity and where the extent of active faults can lead to the assessment of a realistic MCE, this value could be used as an upper limit of the SEE.

Page 45, Section 6.1.5, Earthquake Considerations, following Table 7 add the following:

"Particular attention is drawn to notes 6 and 7 of Table 7. These imply that, where liquefaction of tailings is likely to affect the stability of the dam, the design may need to consider a 1:10,000 AEP earthquake, unless an appropriate risk assessment is undertaken to confirm that an adequate risk profile is achieved with a lower earthquake loading.

For the post-closure case, ANCOLD recommend that all tailings dams are evaluated for stability using the greater of:

- Ground motion from the MCE on known active faults (only where MCE can be calculated reliably), or
- Probabilistic ground motion from a 1 in 10,000 AEP event. This is due to the long life expectation of tailings dams in the post-closure phase. Evaluation of stability can consider the long-term future condition of the closed tailings dam in terms of degree of saturation, state condition of the tailings and the consequent likelihood of liquefaction.

For further guidance on design of tailings dams for earthquake refer to ANCOLD, 2019."

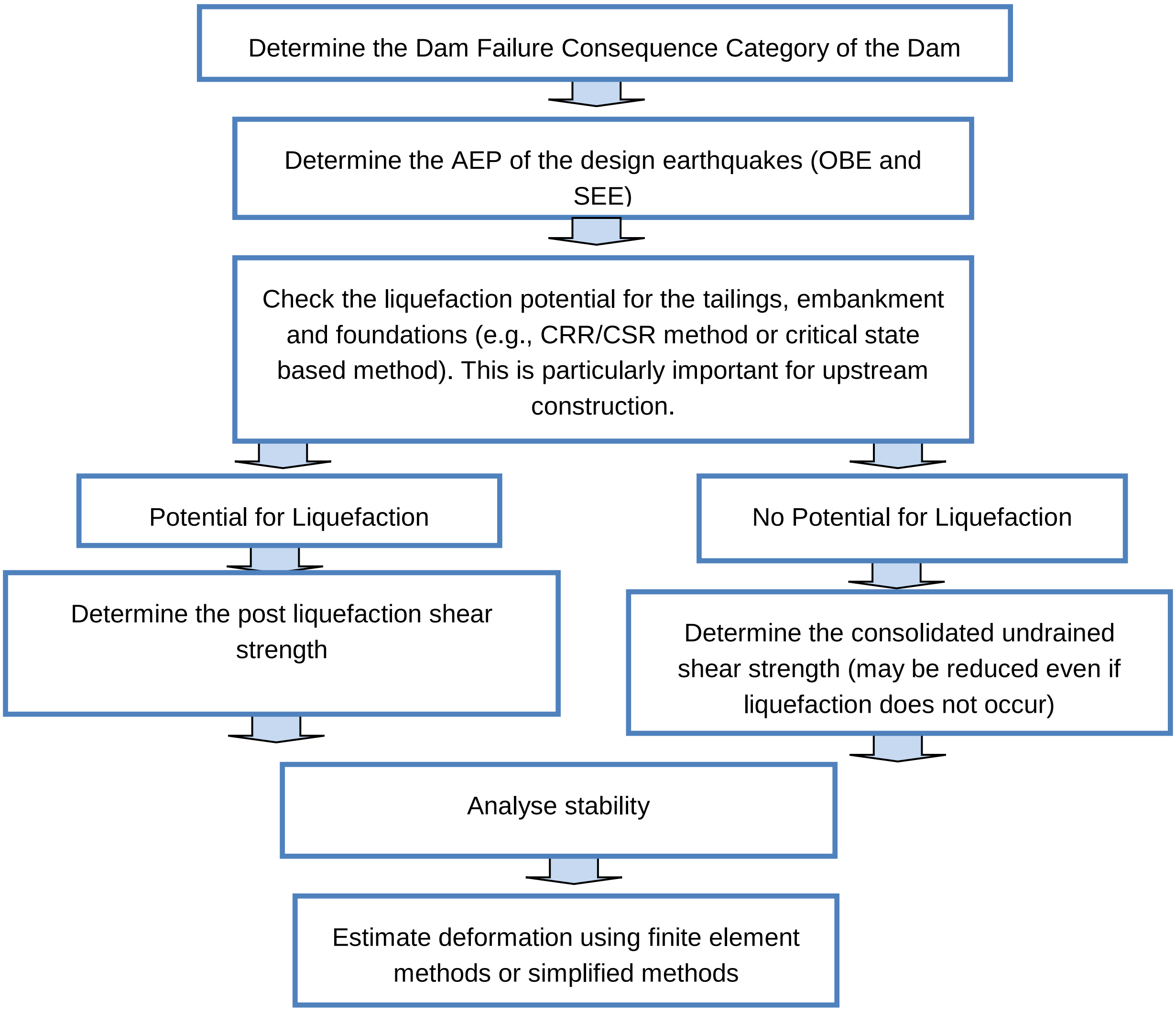
Page 45, Section 6.1.5.1 Stability Analysis under Seismic Loading, first paragraph, line 3:

Replace the sentence "Reference should be made to ANCOLD Guidelines on Design of Dams for Earthquake." with:

"Reference should be made to ANCOLD Guidelines for Design of Dams and Appurtenant Structures for Earthquake (ANCOLD, 2019)."

Page 46, Section 6.1.5.2 Replace Figure 6 with the following:

"Figure 6 Flow sheet for seismic stability analysis



Page 47, Section 6.1.5.2 last sentence of first paragraph:

Replace sentences – "CSR values could be estimated from the simplified procedures of Seed and Idriss (1982) or could be calculated using a more rigorous site response analysis approach, such as that implemented in the SHAKE computer program." and

"An alternative approach would be to use critical state-based liquefaction assessment (Jeffries and Been, 2006)." with:

"CSR values could be estimated from simplified procedures, a more rigorous site response analysis approach, or use critical state based liquefaction assessment (Jeffries and Been, 2006), as described in ANCOLD Guidelines for Design of Dams and Appurtenant Structures for Earthquake (ANCOLD, 2019)."

Page 47, Section 6.1.5.2 last sentence of last paragraph:

Replace sentence – "Guidance on liquefaction assessment and post-seismic stability can be obtained from Duncan and Wright (2005), Fell et al. (2005) and Seed and Boulanger (2008)." with:

Guidance on liquefaction assessment and post-seismic stability can be obtained from ANCOLD Guidelines for Design of Dams and Appurtenant Structures for Earthquake (ANCOLD, 2019).

Page 47, Section 6.1.6 Acceptable Factors of Safety and Deformation, at end of Section, add following:

"Guidance on the need for and type of deformation analysis required in the event of liquefiable materials is presented in Section 3.3 of ANCOLD 2019 Guidelines for Design of Dams and Appurtenant Structures for Earthquake. In summary:

- For High and Extreme Dam Failure Consequence Category dams, and for other dams where the post-seismic factor of safety is lower than 1.1 using a reasonable lower bound for the liquefied strength, conduct numerical analyses to estimate post-earthquake deformations for a range of liquefied strengths and other parameters.
- For cases where the estimated deformation indicates a potential for release of tailings, either design remedial works or, for a new dam, modify the design, so that the estimated deformation is reduced to make the release of tailings unlikely.
- Alternatively, use advanced numerical methods to make more refined estimates of the resulting deformations to confirm that release of tailings is unlikely. This approach should assess results in a conservative manner to take into account the potential short-comings of sampling, testing and modelling."

Page 65, Section 10 References, add:

ANCOLD, Guidelines for Design of Dams and Appurtenant Structures for Earthquake, 2019.

Been, K. 2016, Characterizing mine tailings for geotechnical design. In 5th International Conference on Geotechnical and Geophysical Site Characterisation. Edited by A. McConnell and R. Kelly and B.M. Lehane, Gold Coast, Australia.

Jefferies, M. 2018, Critical state soil mechanics: 125 years of history to current use. In Jenning Lecture 2018. South African Institution of Civil Engineering, Geotechnical Division.

Robertson, P.K. 2010, Evaluation of Flow Liquefaction and Liquefied Strength Using the Cone Penetration Test. Journal of Geotechnical and Geoenvironmental Engineering, 136(6): 842-853. doi:10.1061/(ASCE)GT.1943-5606.0000286.

The Mining Association of Canada in Canada, A Guide to the Management of Tailings Facilities, Third Edition, October 2017.