Impacts of Geoscience Australia's NSHA18 on Seismic Hazard Assessments for Low Annual Probabilities in Australia

Paul Somerville[1], Andreas Skarlatoudis[2], Jeff Bayless,[2] and Don Macfarlane[3]

1. Corresponding author, Principal Seismologist, AECOM, 300 South Grand Avenue, Los Angeles, CA 90071, Email: paul.somerville@aecom.com

2. Project Seismologist, AECOM, 300 South Grand Avenue, Los Angeles, CA 90071, Email: Andreas.skarlatoudis@aecom.com

3. Technical Director – Engineering Geology, AECOM, 2/2 Hazeldean Rd, Christchurch 8024, New Zealand. Email: don.macfarlane@aecom.com

Abstract

This paper considers the impacts of the new National Seismic Hazard Assessment by Geoscience Australia (NSHA18; Allen et al., 2018) on seismic hazard estimates at low annual probabilities in Australia. We discuss these impacts in the context of the draft 2018 ANCOLD Guidelines, with a special focus on Extreme Consequence dams. Using the Risk Based Approach preferred by ANCOLD, the updated spatially distributed earthquake source models that use the NSHA18 earthquake catalogue generally yield significantly lower probabilistic ground motion levels than before, although there are significant spatial variations in this trend. At locations such as Brisbane, Newcastle, Hobart, and Perth, which are remote from potentially active faults, the total probabilistic hazard levels are reduced. At sites near potentially active fault, the incorporation of fault sources from the National Fault Source Model (NFSM) tends to offset the reductions in the contribution of distributed seismic sources. These offsets occur at locations such as Canberra and Melbourne, while in the Adelaide region the fault sources may increase the hazard levels above previous levels at long return periods at some sites. The alternative ANCOLD Deterministic Approach for Extreme Consequence dams requires the use of the Deterministic Safety Evaluation Earthquake (SEE) if it is larger than the Probabilistic SEE, and use of the 85th fractile of the Probabilistic SEE if it is larger than the Deterministic SEE. These requirements are much more conservative than the ICOLD and NZSOLD guidelines for Extreme Consequence dams, especially those located near faults.

Keywords: Active fault, probabilistic seismic hazard analysis, deterministic seismic hazard analysis

INTRODUCTION

This paper considers the impacts of the new National Seismic Hazard Assessment by Geoscience Australia (NSHA18; Allen et al., 2018) for seismic hazard estimates at low annual probabilities in Australia. We discuss these impacts in the context of the draft 2018 ANCOLD Guidelines (ANCOLD is the Australian National Committee on Large Dams), with a special focus on Extreme Consequence dams.

NATIONAL SEISMIC HAZARD ASSESSMENT BY GEOSCIENCE AUSTRALIA (NSHA18)

The NSHA18 project has revised the Australian earthquake catalogue by making corrections to measurements of local magnitude (M_L), and by conversion of the M_L values to moment magnitude M_w (Allen et al, 2017; 2018). The result of this revision has been to approximately halve the frequency of occurrence of earthquakes of a given magnitude in Australia (Allen et al, 2017; 2018). NSHA18 has also generated a National Fault Source Model (NFSM) that provides estimates of slip rates of potentially active faults. These slip rates are now available for a larger number of faults than before (Clark et al. (2011, 2012), and in some cases slip rates have changed. Earthquake frequencies for fault sources are estimated using fault slip rates, not historical earthquakes, so the changes to the earthquake magnitudes do not affect the modelling of fault sources. Consequently, fault sources generally contribute more to the total hazard than before.

The NSHA18 makes it straightforward to use multiple distributed source models from NSHA18 together with the fault sources in the NFSM. ANCOLD (2018) prescribes the use of multiple earthquake source models to address epistemic uncertainty, which yields a suite of alternative seismic hazard curves. The 85th fractile of these hazard curves is used to define the Probabilistic Seismic Evaluation Earthquake (SEE) ground motions for Extreme Consequence dams, as described below.

Generally speaking, we find that updated spatially distributed earthquake source models that use the NSHA18 earthquake catalogue yield significantly lower ground motion levels than before, although there are significant spatial variations in this trend. At locations such as Brisbane, Newcastle, Hobart, and Perth, which are remote from faults, the total hazard levels are reduced. At near fault sites, the incorporation of fault sources from the NFSM tends to offset the reductions in the contribution of distributed seismic sources. These offsets occur at locations such as Canberra and Melbourne, while in the Adelaide region the fault sources may increase the hazard levels above previous levels at long return periods at some sites.

ASSESSMENT OF POTENTIALLY ACTIVE FAULTS FOLLOWING ANCOLD (2018)

ANCOLD (2018) specifies that “active faults (with movement in the last 11,000 to 35,000 years) and neotectonic faults (with movement in the current crustal stress regime, in the past 5 to 10 million years) which could significantly contribute to the ground motion for the dam should be identified, and be accounted for in the seismic hazard assessment.”

An Australia-wide assessment of potential active faulting based on neotectonics data was made by Clark et al (2012). They analysed a catalogue of 333 neotectonic features, 47 of which are associated with named fault scarps. The data were derived from analysis of Digital Elevation Models (DEMs), aerial photos, satellite imagery, geological maps and consultation with state survey geologists and a range of other earth scientists. A neotectonic fault is defined as one that has hosted measurable displacement in the current crustal stress regime (Machete, 2000), i.e. within the last 5-10 Ma in Australia (Sandiford et al., 2004) but is not necessarily an active fault. Verifying these features as active faults (or not) is an ongoing process. The updated NFSM in NSHA18 varies in completeness because sampling is biased by the available databases, the extent of unconsolidated sedimentary cover, and the relative rates of landscape and tectonic processes. Clark et al. (2012) assessed their confidence that each feature in their data base is a neotectonic feature, using the rankings of A: Definite; B: Probable and C: Possible. The distribution of numbers of features in each category is 17%, 32% and 51% respectively. Conditions under which identified faults contribute significantly to seismic hazard in Australia were reviewed by Somerville (2016a) and Somerville et al. (2017).

ANCOLD DETERMINISTIC ASSESSMENT AND RISK ASSESSMENT METHODS

ANCOLD (2018) describes two alternative methods of assessment: a Risk Assessment where the mean probabilistic estimates of ground motion levels are used, and a Deterministic Assessment requiring estimation of a Safety Evaluation Earthquake (SEE), for safety reviews or for design purposes. ANCOLD (2018) prefers use of the Risk Assessment approach. In the Risk Assessment, the hazard curve (describing the hazard level by the annual probability of exceedance as a function of ground motion level) is convolved with the fragility curve of the dam (describing the probability or level of damage as a function of the ground motion level). The contributions of fault sources and distributed earthquake sources are both treated in a probabilistic manner, and are combined to obtain an estimate of the total hazard. The relative contribution of the fault sources at most sites increases because they are unaffected by the reduction earthquake magnitudes in the earthquake catalogue, whereas the contributions of the distributed earthquake sources are reduced at most sites due to the reduction in earthquake magnitudes. Use of ANCOLD (2018) is not expected to have a major impact on Risk Assessments, which use mean estimates of the hazard for all return periods. The same holds true for deterministic assessments for consequence levels below Extreme, because the ground motions are controlled by probabilistic hazard estimates. The use of the NSHA18 earthquake catalogue is expected to reduce the hazard estimates at most sites at all probability levels.

However, in the Deterministic Assessment for Extreme Consequence dams, use is made of both probabilistic and deterministic seismic hazard assessments. The use in ANCOLD (2018) of the term “Deterministic Assessment” in this context has created ambiguity, because in the practice of seismic hazard analysis, a deterministic assessment (Baker, 2013) denotes a scenario-based approach that develops a response spectrum from a single earthquake scenario having a maximum magnitude and closest distance to the site, ignoring its frequency of occurrence. This is in contrast with a probabilistic assessment (Baker, 2013), which considers contributions to the hazard at the site from earthquakes of all magnitudes from all potential earthquake sources including their frequency of occurrence. An ANCOLD (2018) Deterministic Assessment of the SEE uses either the MCE, which is derived from a deterministic assessment (scenario-based approach), or the 1 in 10,000 Annual Exceedance Probability (AEP) hazard derived from a probabilistic assessment, whichever is larger. In this paper, we denote these two versions of a “Deterministic Assessment” as the “Probabilistic SEE” and the “Deterministic SEE” to avoid ambiguity. These two alternative approaches are both used in an ANCOLD (2018) “Deterministic Assessment.”

ANCOLD DETERMINISTIC ASSESSMENTS OF EXTREME CONSEQUENCE DAMS

ANCOLD (2018) specifies that, for Extreme Consequence dams, “the Safety Evaluation Earthquake (SEE) is defined by the greater of the ground motions from the median MCE on known active faults or the 85th fractile of the probabilistic ground motion having a 1 in 10,000 AEP.” This guideline requires the use of larger SEE ground motions than before for both methods used to develop the SEE, for the reasons shown in Figure 1 and explained next.

If the Extreme Consequence dam site is sufficiently distant from identified potentially active faults, the deterministic Maximum Credible Earthquake (MCE) which we call the Deterministic SEE, will be lower than the Probabilistic SEE. Then the SEE spectrum will be represented by the 85th fractile of the 10,000 year return period uniform hazard probabilistic spectrum. (Such a spectrum is illustrated on the left side of Figure 1 for the case of a near-fault site). Previously, the median ground motion level (50th fractile) of that spectrum was used. This increase in the Probabilistic SEE level may not be entirely offset by the reductions that come from the revised NSHA18 earthquake catalogue.

If the Extreme Consequence dam site is sufficiently close to identified potentially active faults (Somerville et al., 2013; Somerville, 2016a), the Deterministic MCE (the deterministic SEE) will exceed the Probabilistic SEE (i.e. 85th fractile of the probabilistic 10,000 year average return period (ARP) ground motion), as illustrated on the right side of Figure 1. Ironically, because of the significant net reduction in the Probabilistic SEE noted above, there is an increased likelihood that the Deterministic MCE (SEE) will be larger than the Probabilistic SEE and will therefore control the SEE, and significantly exceed the present SEE level at near fault dam sites. We expect that the Deterministic SEE will correspond to return periods much longer than 10,000 years (Somerville, 2016b), as indicated on the right side of Figure 1, where it approximately corresponds to a return period of 100,000 years. This increase will not be offset by the changes in earthquake occurrence rates in the NSHA18 earthquake catalogue because the Deterministic approach is based on potential faults and ignores earthquake occurrence rates. Unless offset by the revision of the magnitudes in the earthquake catalogue, it is expected that new Deterministic SEE ground motion levels will exceed current values at many near fault dam sites. Much more careful faulting hazard assessments, potentially including field assessments of fault activity, may be warranted if the Deterministic Assessment is used because of the potentially large impact of identified faults on the Deterministic SEE, as illustrated on the right side of Figure 1.

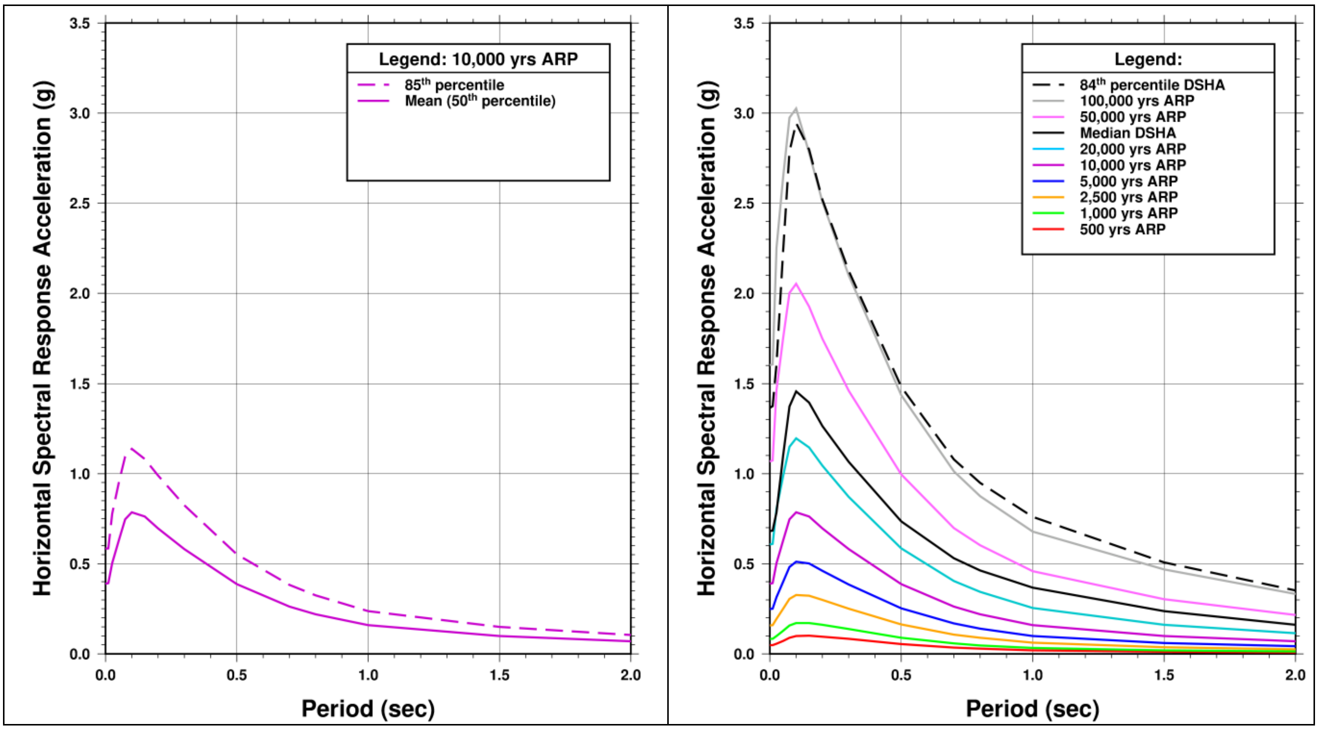

Figure 1. Left: Median and 85th fractile of the Probabilistic SEE response spectrum (for 10,000 year ARP) at a near fault site. Right: Comparison of probabilistic and deterministic (DSHA) response spectra at the near fault site. The solid black line is the median deterministic response spectrum, which is not formally specified in ANCOLD (2018) but in practice is used, and constitutes the MCE and Deterministic SEE, and the dashed black line shows the 84th percentile of the deterministic response spectrum, as specified for use in ICOLD (2016) and NZSOLD (2015).

The 85th fractile of the Probabilistic SEE spectrum (left panel of Figure 1) represents the ***epistemic uncertainty*** in the true value ("best estimate") of the Probabilistic SEE; there is only a 15% chance that the true value lies above the 85th fractile. The 84th percentile of the Deterministic SEE (right panel of Figure 1) represents the ***aleatory (random) variability*** in the response spectral acceleration for the scenario earthquake that defines the MCE and the Deterministic SEE. In any given occurrence of the MCE earthquake, there is only a 16% chance that the actual response spectral acceleration at each ground motion period will randomly exceed the 84th percentile ("near worst case") level in that realisation of the MCE.

COMPARISON OF ANCOLD (2018) WITH ICOLD (2016) AND NZSOLD (2015) APPROACHES TO THE SEE FOR DETERMINISTIC ASSESSMENTS OF EXTREME CONSEQUENCE DAMS

ICOLD (2016) states that for Extreme Consequence dams, "the SEE ground motion parameters should be estimated at the 84th percentile level if developed by a deterministic approach, and need not have a mean Annual Exceedance Probability (AEP) smaller than 1/10,000 if developed by a probabilistic approach." Deterministically derived MCE ground motions are defined by ICOLD (2016) as the "most severe ground motions" from the "largest reasonably conceivable earthquake magnitude that is considered possible along a recognized fault ... under the presently known or presumed tectonic framework". It further states that "Deterministically-evaluated earthquakes may be more appropriate in locations with relatively frequent earthquakes that occur on well-identified sources, for example near plate boundaries." As pointed out by Somerville (2016c), this implies that the SEE in Australia should be evaluated probabilistically because in Australia there are no "locations with relatively frequent earthquakes that occur on well-identified sources, for example near plate boundaries." The fact that only 17% of the neotectonic features identified by Clark et al. (2011, 2012) are considered by them to be definitely active reinforces this view. Further, NZSOLD (2015) states that the SEE is "the 84th percentile level for the Controlling Maximum Earthquake (equivalent to MCE in ANCOLD 2018) if developed by a deterministic approach, and need not exceed the 1 in 10,000 AEP ground motions developed by a probabilistic approach." If the SEE is developed by a probabilistic approach, ICOLD (2016) and NZSOLD (2015) do not specify the use of the 85th fractile, and it is assumed that they intend that the mean hazard level be used.

ANCOLD (2018) is thus much more conservative than the ICOLD and NZSOLD guidelines for Extreme Consequence dams, by requiring the use of the Deterministic MCE (Deterministic SEE) if it is larger than the Probabilistic SEE, and by requiring the 85th fractile of the Probabilistic SEE if it is larger than the Deterministic SEE, as illustrated in Figure 1. This requires careful consideration of which (if any) identified faults should be considered to be potentially active for the purpose of evaluation of the Deterministic SEE. This may prompt field investigations of potentially active faults to assess their recency of activity and hence whether they need to be considered in the deterministic approach to estimating the SEE. ANCOLD (2018) clearly states a preference for treating very large deterministic ground motions that have very low probability levels in a Risk Assessment, which is probabilistically based, and is more compatible with the probabilistic approach following ICOLD (2016) and NZSOLD (2015) practices, and Somerville (2016c).

CONCLUSIONS

We have examined the implications of the new NSHA18 (Allen et al., 2018) on seismic hazard estimates at low annual probabilities in Australia, and assessed this impact in the context of the draft 2018 ANCOLD Guidelines, with a special focus on Extreme Consequence dams. Using the Risk Based Approach preferred by ANCOLD, the updated spatially distributed earthquake source models that use the NSHA18 earthquake catalogue generally yield significantly lower probabilistic ground motion levels than before, although there are significant spatial variations in this trend. At locations such as Brisbane, Newcastle, Hobart, and Perth, which are remote from faults, the total probabilistic hazard levels are reduced. At near fault sites, the incorporation of fault sources from the NFSM tends to offset the reductions in the contribution of distributed seismic sources. These offsets occur at locations such as Canberra and Melbourne, while in the Adelaide region the fault sources may increase the hazard levels above previous levels at long return periods at some sites.

The alternative ANCOLD Deterministic Approach for Extreme Consequence dams requires the use of the Deterministic Safety Evaluation Earthquake (SEE) if it is larger than the Probabilistic SEE, and use of the 85th fractile of the Probabilistic SEE if it is larger than the Deterministic SEE. At Extreme Consequence dam sites that are sufficiently distant from potentially active faults such that the Probabilistic SEE exceeds the Deterministic MCE (Deterministic SEE), ANCOLD (2018) increases the seismic hazard levels due to the newly introduced use of the 85th fractile of the probabilistic hazard for 10,000 year ARP. However, this increase may be outweighed by the decreases caused by changes in the earthquake magnitudes, resulting in a net reduction in ground motion levels at most rock sites in Australia that are not near faults.

However, by using the larger of the deterministic or probabilistic approach to establishing the SEE following ANCOLD (2018), the deterministic Maximum Credible Earthquake (MCE) for Extreme Consequence dams that are sufficiently close to identified faults will exceed the Probabilistic SEE. Ironically, because of the significant net reduction in the Probabilistic SEE noted above, there is an increased likelihood that the Deterministic MCE will be larger than the Probabilistic SEE and will therefore control the SEE, and significantly exceed the present SEE level at near fault sites. The revised NSHA18 earthquake catalogue will have no reduction effect because the deterministic approach ignores earthquake frequencies. The resulting Deterministic SEE ground motions may have average return periods greatly exceeding 10,000 years. This may prompt field investigations of potentially active faults to assess their recency of activity and hence whether they need to be considered in a Deterministic Assessment, or prompt the alternative use of the Risk Assessment approach as recommended by ANCOLD (2018).

By requiring the use of the Deterministic SEE if it is larger than the Probabilistic SEE, and by requiring use of the 85th fractile of the Probabilistic SEE if it is larger than the Deterministic SEE, the ANCOLD (2018) guidelines for Deterministic Assessments are much more conservative than the ICOLD and NZSOLD guidelines for Extreme Consequence dams, especially those located near faults.

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