Reply to reviewer #1 of "Risk-informed representative earthquake scenarios for Valparaíso and Viña del Mar, Chile"

Reviewer comments are repeated here in black, our response is in blue font. Text from the paper is given in *italics*.

RC1: 'Review of nhess-2023-186', Anonymous Referee #1, 19 Nov 2023

The manuscript aims to select representative earthquake scenarios for the communication of seismic risk and for the planning of risk mitigation actions. The authors define these scenarios as the scenarios which are most likely to cause a certain regional loss value. For this purpose, they apply a methodology that was proposed by two of the authors in a separate manuscript. This methodology is claimed to require less simulation runs than a conventional loss disaggregation, which commonly relies on a large stochastic event catalog.

The topic is interesting and within the scope of NHESS. The manuscript is well written and shows the expertise of the authors. It is also clear and generally well-structured. Yet, some parts of the manuscript would benefit from additional explanations and discussions to improve its clarity and its contribution to the field. Please see some suggestions below.

We thank the reviewer for their positive feedback and useful comments that help us in clarifying our contributions and in improving the manuscript.

Major comments

1. The y-year loss refers to the loss value that is (on average) exceeded every y years. Importantly, it does not refer to the loss value, which (on average) occurs every y years. The identified scenario, however, relates to the most likely scenario that causes this loss value (and not an exceedance of this loss value). Therefore, the link between the return period y and the identified scenario is not straightforward. I am sure that the authors are well aware of this important difference, but the readers (and more importantly, potential users of the identified scenarios) would certainly benefit from additional explanations on this aspect.

   The loss value l_t is the t-year loss, i.e., the loss that on average is exceeded every t years, as the reviewer states. It is selected based on the loss exceedance function. We define a representative earthquake scenario as the mode of the conditional density given this loss, i.e., the occurrence of the l_t loss. However, one can also define it as the mode of the conditional density given the exceedance of that loss.

   A discussion about the differences between the exceedance and occurrence approaches is presented in Fox et al (2016) for hazard disaggregation. Works on loss disaggregation (Goda et al, 2009; Jayaram & Baker, 2009) use the exceedance approach. To the knowledge of the authors, there are no references discussing the differences in the exceedance and occurrence approach for loss disaggregation.

Realizing that gap, we modified the paper sections to provide better insight into this difference. For example, in the introduction part:

The above concepts were extended to loss disaggregation to find earthquake scenarios in terms of magnitude and hypocentral distance that exceed a loss threshold for building stocks (Goda and Hong, 2009) or infrastructure (Jayaram and Baker, 2009b) (...). The definition of Rosero-Velásquez and Straub (2022) differs from the loss disaggregation presented by Goda and Hong (2009) and Jayaram and Baker (2009b) because the latter define the representative scenario as the most likely one to exceed the t-year loss. In this contribution, we compare the two definitions and argue that a definition in terms of the occurrence of the t-year loss is more consistent in most cases.

In Section 2, we introduce the definition in terms of exceedance:

An alternative definition can be formulated in terms of loss exceedance instead of loss occurrence:

$$\theta_t^{exc} = \max_{\theta} f_{\Theta|L}(\theta | L \geq l_t) \qquad (4)$$

In such case, Eq. (4) defines the scenario that is most likely to exceed l_t. This is the definition corresponding to the classical loss disaggregation proposed by Goda and Hong (2009) and Jayaram and Baker (2009b). We note that with this definition, in general, the scenario representative of a t-year loss will have a loss return period higher than t. Hence, we find its interpretation more difficult, and prefer the definition in Eq. (3). A similar observation was made by Fox et al. (2016) for the case of hazard disaggregation. Nevertheless, we propose algorithms to evaluate the representative scenarios according to the two definitions and compare the resulting scenarios.

2. To resolve the above-mentioned issue, the scenario could be identified as the one that contributes most to the losses larger than the y-year loss, ly. In other words, one would aim to find the mode of p(theta | L > ly) rather than the mode of p(theta | L = ly). For hazard disaggregation, for example, Fox et al. (2016) note that such an exceedance-based approach is preferable if one aims to establish a direct link to a ground motion with a specified return period. The results, shown in Figure 7, suggest that the authors performed loss simulations for the entire stochastic event catalog. With these simulations, it should be straightforward to perform such an exceedance-based disaggregation and to compare the resulting scenarios with the already identified ones. Such a comparison would be very valuable and, given that it does require very little additional effort, I recommend that the authors

include a discussion on this aspect in the main body of the paper. The detailed results of this comparison could be shown in an appendix.

This is a recommendation also made by Fox (2023). More specifically, we believe the reviewer might refer to the following statement made in Fox et al (2016): "The exceedance approach is consistent with conventional response history analyses, which are used to determine the expected response for ground motions defined by a certain return period for exceedance". However, Fox et al (2016) also state that "perhaps because of its ready availability, this form of disaggregation is often used directly as an aid in ground-motion selection in PBEE. However, this is not consistent with the typical seismic analysis that follows, which is used to determine the response of a structure at a given intensity (i.e. for $Sa = x_i$ and not $Sa > x_i$, as required in the PEER PBEE framework)". It should be noted that Fox (2023) did not find significant differences between the exceedance and occurrence approaches in the disaggregation results applied to a real case in New Zealand. However, it could be instructive to compare both approaches in our case. Whereas he limits the analysis to hazard disaggregation, we here follow this recommendation for loss disaggregation.

Following your comment, we computed the representative earthquake scenarios with the exceedance approach for the toy example and – as expected – found that they are slightly more extreme than the ones computed with the occurrence approach:

(a) Loss occurrence approach *(b) Loss exceedance approach*

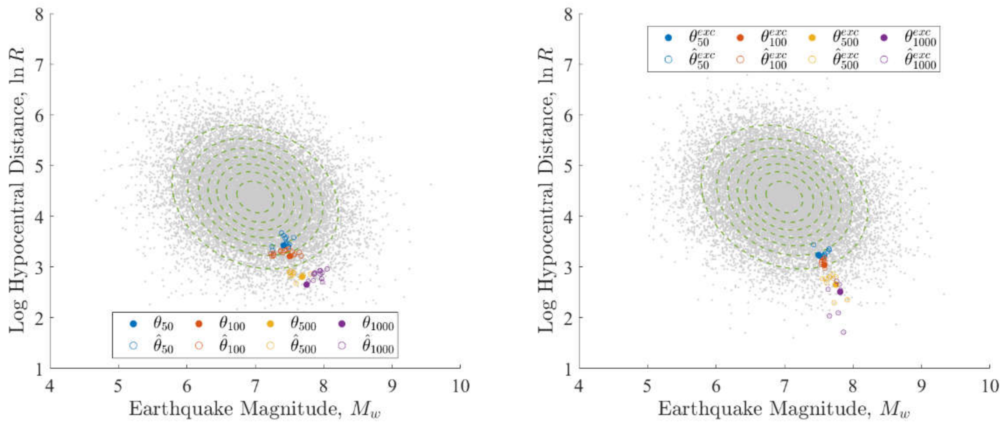

Figure 4. Numerical approximation of the representative earthquake scenarios. On panel (a) the representative scenarios computed with the loss occurrence approach, $\hat{\theta}_t$, and on panel (b) the ones computed with the loss exceedance approach, $\hat{\theta}^{exc}{}_t$. The representative earthquake scenarios correspond to four different return periods t = 50, 100, 500, 1000 years, based on a Monte Carlo sample of scenarios. Each return period is represented by a different color. For each return period, the 20 approximations $\hat{\theta}_t$ (resp. $\hat{\theta}^{exc}{}_t$), corresponding to 20 experiments, are the colored empty circles, and the corresponding exact solutions are depicted by filled circles. The grey points are the

scenarios of the catalog, and the dashed contours represent the PDF of the source parameters.

Our findings go in line with those of Fox et al (2016) for hazard disaggregation. We have extended the discussion section of the paper to make the case why we consider the occurrence approach to be more suitable for scenarios defined in terms of loss return periods:

We presented the evaluation of representative earthquake scenarios based on the loss occurrence and the loss exceedance approach; the latter coincides with the loss disaggregation method (Goda and Hong, 2009; Jayaram and Baker, 2009b). In the illustrative example of Section 4.2, we compare the results of the two approaches. For the case of hazard disaggregation, it has been proposed in the literature that the results of both approaches should be reported (Fox, 2023). However, we decided against reporting the scenarios of the exceedance approach for the Valparaíso and Viña del Mar communes, to avoid confusion. We find the loss occurrence approach to have a more intuitive interpretation. Scenarios identified with this approach correspond to a loss that is the t-year loss, which can be reported jointly with the scenarios. They are the most likely scenarios leading to this value (which on average is exceeded once in t years). By contrast, we find it difficult to communicate the meaning of the scenarios with the loss exceedance approach, and we believe it will be mostly misunderstood. Scenarios obtained with the loss occurrence approach can be described as "representative of a loss that is exceeded on average once in t years". For the loss exceedance approach, one would need to describe scenarios as "representative of the losses that would occur when conditioning on a loss at least as large as the one that would be exceeded once in t years", which seems too convoluted to communicate effectively. Nor is it easy to conceive of a risk management activity for which such a definition would be more appropriate.

3. I agree that scenario-based analyses are valuable for many risk mitigation actions, as well as for risk communication purposes. Yet, the manuscript would benefit from some comments on potential pitfalls related to the use of a single representative scenario. For example, emergency managers may use the estimated spatial distribution of damage and losses from a representative scenario to optimize the placement of machinery and personnel before an event. What if another event (with a different distribution of damage and losses) is almost as likely to cause the considered return period loss. Is the proposed methodology capable of identifying such alternative scenarios?

   We added a paragraph in the discussion section to address this point:

   Although single representative scenarios are valuable for risk mitigation and communication purposes, they also have several limitations. For example, designing effective risk mitigation strategies, such as resource allocation before the event, using a single representative scenario would result in solutions tailored to the spatial distribution of damage of the specific selected scenario. Thus, better strategies could be defined by considering multiple scenarios, even for the same loss return period.

We had also written in the discussion (L408-409) that *for practical risk management tasks it is recommended to use the historic events jointly with the identified scenarios, in particular for the residential building stock case.* That is, the proposed methodology can find alternative scenarios to historical ones, and should complement (not replace) reference scenarios utilized for risk management and communication tasks.

4. A large part of the manuscript focuses on the description of the scenario selection algorithm, which is quite different to the conventional loss disaggregation approach. Yet, the conclusion section contains very little – if any – information on the advantages and limitations of the proposed method (in comparison with the conventional one). I recommend that the authors try to improve the clarity of their conclusions. The summary in the discussion section is much appreciated.

   We extended the discussion section to address this point:

   To evaluate the representative scenarios, we adapted the methodology of Rosero-Velásquez and Straub (2022). The methodology leads to lower computational cost in terms of loss evaluations compared to the classical loss disaggregation. By incorporating active learning, the methodology concentrates the conditional loss evaluations around the scenarios that most likely produce the t-year loss value l_t. This concentration of samples around the solution and the smooth approximation of the conditional density with KDE make the methodology more suitable for selecting representative scenarios with a loss occurrence approach. For this approach, the classical loss disaggregation has to rely on the numerical derivative of the empirical CDF (Baker et al., 2021).

   We also added a dedicated section called "Computational costs" in the results:

   In terms of loss evaluations, we required one evaluation per scenario in the catalog, for constructing the loss exceedance function with event-based earthquake risk assessment. That corresponds to 2×10^4 loss evaluations. In addition, during the AL stage, around 10 iterations were necessary to achieve the convergence criterion of Eq. (25), each of them consisting of 160 new loss evaluations (n_s = 2 scenarios evaluated n_l = 20 times, for each of the n_t = 4 return periods). Therefore, 1600 loss evaluations are needed to find the representative earthquake scenarios for 4 different return periods.

   For comparison, Goda and Hong (2009) report that they use a total of 5×10^6 loss evaluations for the "classical" loss disaggregation. Furthermore, they only evaluate the scenarios only with the loss exceedance approach. Extending the loss disaggregation approach to the loss occurrence approach will likely require additional evaluations. Additionally, the computation cost of the loss disaggregation approach scales exponentially with the number of parameters describing seismic scenarios. Hence the approach will not be applicable to problems in which earthquake scenarios are described by more than 3 or 4 parameters.

Minor comments

1. Over the past years, the term Ground Motion Model (GMM) seems to be more commonly used than the term Ground Motion Prediction Equation (GMPE). Mainly, because most of the modern empirical GMMs do no longer consist of a single equation. See also the notes of David Boore for some terminological discussion (Boore, 2020), and feel free to adapt it.

   We replaced GMPE with GMM.

2. Lines 94-97: Do the authors have any quantitative comparison (in terms of computation time) between the two loss disaggregation methodologies? This would be interesting and certainly help to highlight the advantages of the proposed method.

   Please refer to the reply to major comment Nr. 4.

References

Boore, D. M. (2020): Thoughts on the acronyms “GMPE”, “GMPM”, and “GMM”, available at https://daveboore.com/daves_notes.html

Fox, M. J., Stafford, P. J., and Sullivan, T. J. (2016): Seismic hazard disaggregation in performance-based earthquake engineering: occurrence or exceedance?, Earthquake Engineering & Structural Dynamics

Fox, M. (2023). Considerations on seismic hazard disaggregation in terms of occurrence or exceedance in New Zealand. Bulletin of the New Zealand Society for Earthquake Engineering, 56(1), 1–10