REVIEWER 2

This manuscript perfectly describes the aggregation of all current knowledge and methods for characterizing seismic hazard, vulnerability and risk, applied to Switzerland. This manuscript compiles several decades of work, from different groups (seismology, engineering seismology, earthquake engineering and even communications), for a single product as target: the seismic risk map of Switzerland. The authors are all experts in their field, and have contributed in one way or another to the definition of one of the strategies in their area of expertise followed in this study: definition of source zones, selection of GMMs and associated logic tree, characterization of site effects, definition of vulnerability curves and loss models. Each step references a series of peer-reviewed publications, giving scientific validity to the study.

So why this article?

1. On reading this manuscript, I fail to see the scientific contribution or the added value for publication in NHESS. Throughout the manuscript, reference is made at every step to Wiemer et al. 2023, and the question arises as to how this article compares with Wiemer's paper and what is the original contribution with respect to this 2023 paper?.

   We would like to primarily refer to our reply to the first reviewer's general assessment. But in short and without repeating our other response, we see the following as contributions of this article:

   - Quantification of earthquake risk estimates for Switzerland for different loss types (economic building and contents loss, fatalities, injuries, displaced population); breakdown by canton or municipality (Fig 10); breakdown by building typology (Fig 11).

   - Presentation of the multidisciplinary approach adopted by the Swiss Seismological Service for the development of Switzerland's national earthquake risk model. Summary of key elements and references to the technical report for interested readers.

   - Various insights, e.g. discussion and statistics of the composition of the modelled building exposure, differences with other models and reasons for them (we will add a couple of additional plots, see response to comment 2.), communication concept.

Wiemer et al. (2023) is the ~200 page technical report that describes the model in detail. We refer to it in the same way we would to an electronic supplement, since the full details of a model of this scale cannot be summarized in a short article.

2. A few attempts at "testing" with recently published models show that, in the end, the estimate is neither right nor wrong, good nor false,… but rather overestimates one and underestimates the other, without it being clear why. This testing section could have been extended, which would have improved the novelty of this manuscript: by identifying the source of the differences, by discussing the need for a regional model versus a local model, by discussing some options taken (notably in ESRM20) or by extending the comparison between models to specific target areas for which the site conditions and the exposure model are (perfectly!) known (e.g. Valais or maybe the Basel urban area).

We will extend the comparison section by adding the figure below to reinforce the points made in the pre-existing paragraph (difference in exposure values, resolution of site amplification model).

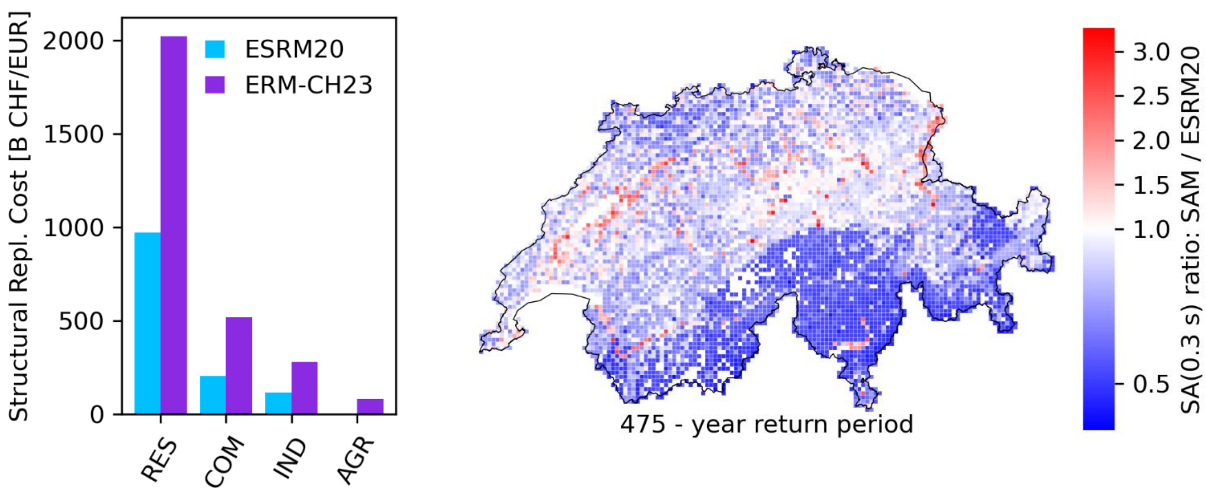

Figure 13. Comparison of total structural replacement cost between ESRM20 and ERM-CH23 (left); Ratio of 475-year SA (0.3 s) values on soil predicted by the SAM component of ERM-CH23 and ESRM20 across Switzerland.

With respect to the reviewer's last point, unfortunately, there are no specific areas where either the site conditions or the exposure model are perfectly known. The site model might be more reliable in certain areas, although still uncertain and ground motion will still be largely impacted by the underlying GMMs. The exposure model would also be much more uncertain if we were to focus on a smaller region, since building materials are assigned based on survey statistics. For larger exposures, the estimates are likely to be robust due to the law of large numbers and averaging out of errors. But for smaller areas, they would be less reliable, not necessarily more.

3. The issue on the contribution of each step in the final uncertainties could also have been developed. We've known for some time that the uncertainty linked to the hazard assessment is certainly the factor with the greatest impact: this message now seems self-evident, but has yet to be confirmed. In particular, this may be due to a lack of understanding of vulnerability and exposure: if we were to benefit from the same amount of experimental data as those used for ground motion modelling (the number of which has increased enormously over the last 20 years), wouldn't we end up with a shared contribution of hazard and exposure to the final uncertainty? Or is the variability of ground motion intrinsically (non-epistemic) greater than that of structural response? This question, debated and simulated thanks to the logic trees defined herein, could have been tested, bringing a novelty to this study.

   We agree with the reviewer that vulnerability (and to, likely, some lesser degree exposure) modeling involves a great deal of uncertainty that is currently not being modelled. We do not necessarily agree with the notion that hazard uncertainty should be expected to completely overpower any uncertainty that would be expected from vulnerability modeling, were the latter modelled thoroughly. Some of the challenges and size of uncertainties in vulnerability assessment are for instance discussed in (Cremen and Baker, 2020; Silva et al., 2019).

   - Cremen G and Baker JW (2020) Variance-based sensitivity analyses and uncertainty quantification for FEMA P-58 consequence predictions. Earthquake Engineering and Structural Dynamics (May 2019): 1–20.
   - Silva V, Akkar S, Baker J, et al. (2019) Current challenges and future trends in analytical fragility and vulnerability modeling. Earthquake Spectra 35(4): 1927–1952.

   Modelling the epistemic uncertainty on the vulnerability component is still a barrier that the earthquake risk modelling community (and us here) has not overcome (for large scale risk studies). Before delving into that though, we would like to stress that we are referring to systematic differences (bias) to the mean vulnerability function that describes the behavior of each building class. The reason for this bias could be methodological/modeling assumptions, unrepresentative samples or building archetypes, etc. Other types of uncertainties that characterize individual buildings (e.g. material uncertainty) but are not systematic (building-class wide), might have a huge effect on the risk estimates of individual buildings (or small building portfolios), however they are expected to have small influence on the regional results (since these kind of errors average out, as long as the mean vulnerability curve is unbiased).

   To model the first type of systematic uncertainties (e.g. as a logic tree) there are the following obstacles:

- The development of vulnerability models is typically analytical, since empirical data (even more so for Switzerland) are lacking. Therefore, it requires a huge amount of effort and domains of expertise (concrete, steel, masonry, timber, etc buildings) that usually lie with different groups.
- One could envisage introducing some uncertainty based on engineering judgment by shifting the original vulnerability curves to the left or right with appropriate weights. This can be done if one thinks there could be systematic biases in the methodology used to derive the fragility model (although it is difficult to guess the direction and magnitude of such possible bias). On the other hand, (arguably much larger) uncertainties that are not tied to the methodology but to the data and/or assumptions used for modeling different building types would be independent. Therefore, one would need to create multiple logic tree branches where let's say an upper vulnerability model for reinforced concrete mid-rise is combined with a lower vulnerability model for stone masonry low-rise, etc. These combinations are intractable and difficult to model. Sampling could be an option, although (1) OpenQuake at the moment does not allow for that, (2) convergence issues would then arise when looking at the results by building typology.
- In any case, none of this would address directly the reviewer's comment, since it would be based purely on judgement and assumptions rather than on data, which, as the reviewer also says, are missing when it comes to vulnerability modeling.

Finally, we should say that regardless of the above, testing any of that would be a paper of its own. This is outside our scope here, which is the presentation of the ERM-CH23 model and mainly of the obtained estimates of seismic risk in Switzerland.

4. Finally, by compiling and aggregating previously published studies, much information is missing in order to follow the flow of the manuscript: GMM equations are missing, parameters characterizing site conditions are missing, descriptions of vulnerability models are missing etc... and in the end, the paper looks like a compilation of studies, not a scientific paper.

- We will an Appendix with the GMM equations comprising the logic tree.
- The parameters characterizing the site conditions are actually mentioned in the paper.
- We will greatly expand the section on the developed consequence model (see response to comment 10.).

All in all, we fully understand the reviewer's perspective in this comment, although it is the nature of this work (risk modeling in general) that relies on multiple components that come from other studies and cannot be summarized in a single article.

For instance, as requested, we have added an appendix with the GMM equations used. These have been published in scientific articles and are still not summarized here (and it would not be possible to summarize 18 GMMs and 4 IPEs). Likewise, almost every published study on seismic hazard and risk assessment cites the used GMM equations without describing them further.

The site amplification model developed for ERM-CH23 has also recently been published in a peer-reviewed journal. Instead of just citing like we do with the GMMs, a high-level overview is provided (because of its direct relevance; and because of the fact it is a single model rather than 18, and hence easier to give an overview). Perhaps this gives the impression of missing information, but is it really much different?

That said, again, we want to state that we understand the perspective of the reviewer, but if model components cannot be summarized and referred to other publications, it would be impossible to publish articles on seismic risk. And while methodologically, this particular paper, constitutes primarily an application of the state-of-the-art risk framework, it combines the various individual high-quality components (e.g. amplification layer, exposure) derived as part of the ERM-CH23 project (some of which derived through novel approaches), to reach an updated view of seismic risk for the country of Switzerland (e.g. compared to ESRM20 or GEM that at the time used less detailed datasets for Switzerland). Lastly, we would argue that our paper (together with the cited report) gives significantly more information than other recent similar publications.

Some general comments:

5. Introduction lines 22-27: very classic, and in a special issue like this one, we're convincing the convinced. In my opinion, a little added value, such as the fact that natural hazard management programs save $3-4 on average for every $1 invested, goes a long way towards justifying the production of seismic risk maps like the one presented here.

We thank the reviewer for his suggestion. We will modify the opening paragraph to add the reference to the study of NIBS that we were not previously aware of:

"*Natural hazards can cause widespread damage, loss of life, and disruption to critical services such as water, power, and transportation. Earthquake risk mitigation programs are effective, and as cities and populations continue to expand, they become increasingly vital to safeguard lives, infrastructure, and economic stability. A study from the National Institute of Building Sciences in the US estimated that Federal Mitigation Grants for earthquake hazards save 3 dollars per 1 dollar spent (National Institute of Building Sciences, 2019). Catastrophe risk models, in particular, can aid governments and other stakeholders in […]*"

6. Line 52-55: " ... is considered moderate with three to four earthquakes a day.... " This sentence (and many others) is too vague, certainly because of the systematic reference to already published papers. Relying on previous studies should not compromise understanding of the article as a whole.

While we did not perceive this as vague at the time of writing, we certainly want to clarify any statements that appear vague. It is not entirely clear here what references to published studies the reviewer refers to in this segment. We would be happy to make further amendments, if the statement is still not clear. For now, we will change it from:

"*Overall, the seismicity in the country is considered moderate with three to four earthquakes a day recorded on average within the country and around its borders by the Swiss Seismological Service (SED)"*

to:

"*Overall, the seismicity in the country is considered moderate with three to four earthquakes a day recorded on average within the country and around its borders by the monitoring network of the Swiss Seismological Service (SED; www.seismo.ethz.ch), the federal agency responsible for monitoring earthquakes in Switzerland and its neighboring regions."*

7. Line 114: " site condition indicators... " which ones?

We have rephrased this sentence, hopefully our amendment has improved clarity. The sentence originally read:

"*The site condition indicators, including the lithological classification of Switzerland, multiscale topographic slope, and depth-to-bedrock, were combined with […]*".

We will change it to:

"*The selected site condition indicators (lithological classification of Switzerland, multiscale topographic slope, and depth-to-bedrock), were combined with […]*".

8. "Line 161: "...collected from other sources..." which ones?

We will add the following references:

Mouyiannou et al., 2014; Ottonelli et al., 2020; Rossi et al., 2021; Cardone, 2016; Cardone and Perrone, 2015; Magenes and Calvi, 1997; Avila et al., 2012.

9. Figure 1 is not cited in the body of the manuscript

Thank you for noticing it, we will cite it within the text.

10. Line 162: please specific the macroeconomic model. Do you think that structural/nonstructural damage-to-loss ratio from US can be transferred to Switzerland? In particular, this ratio could have been explored in greater depth with a few tests, so as to add something new to the study

We will largely expand this section by adding an additional page on the damage-to-loss ratio model. The full new section is given below:

"*A consequence model that relates damage to loss has been compiled for application to Switzerland (Wiemer et al., 2023). Different approaches were used for each of the five loss types of interest, depending on the availability of data. In brief, injuries and deaths were modelled based on the estimates given by HAZUS (FEMA, 2010), NCPD (2018), and Spence et al. (2007). Estimates of displaced population were instead adopted from the empirical data harmonized by the Italian National Civil Protection Department (NCPD, 2018). Displaced population in ERM-CH23 refers to households that have been displaced either in the short- or long-term. Content damage-to-loss estimates have also been adopted from the literature, and more precisely from HAZUS (FEMA, 2010).*

On the other hand, the structural/nonstructural damage-to-loss functions have been derived analytically adopting the loss estimation methodology of FEMA P-58 (FEMA, 2018). For each building typology, the prescriptive damage states as per the EMS-98 scale were matched to associated structural demand thresholds sourced from the literature (Wiemer et al., 2023). Archetype blueprints were used to infer quantities and features of structural elements such as load-bearing masonry walls, spandrels and slabs. The quantity estimator tool of FEMA P-58 was also used to determine the non-structural component quantities with uncertainty. Fragility and consequence functions for damageable structural and non-structural components, present in Swiss buildings, that were not available in FEMA P-58, were gathered and collated from other sources (Mouyiannou et al., 2014; Ottonelli et al., 2020; Rossi et al., 2021; Cardone, 2016; Cardone and Perrone, 2015; Magenes and Calvi, 1997; Avila et al., 2012). The repair and replacement costs were adjusted using a macro-economic model in view of the construction dynamics between the reference country (from which cost functions were available, i.e. Italy or the US) and Switzerland.

The repair cost conversion factor (RCCF) to be multiplied with the original (reference country) cost estimates was obtained as per Equation (1), building upon previous suggestions by Porter et al. (2015), Papadopoulos et al.(2019) and Silva et al. (2020a):

$$RCCF = (r_{lab} \cdot f_{lab} / r_{prod}) + (r_{mat} \cdot f_{mat}) + r_{m\&p} \cdot f_{m\&p} \qquad (1)$$

Here, f_{lab}, f_{mat} and $f_{m\&p}$ represent the proportion of the total repair cost associated with labour, materials, and margins and preliminaries, respectively, in the reference country (from which the cost is being adapted). On the other hand, r_{lab}, r_{mat} and $r_{m\&p}$ denote estimated ratios of the costs of labour, material, and margins and preliminaries between

Switzerland (numerator) and the reference country (denominator). These parameters were determined following an extensive survey of both national and international sources, including the statistics bureaus of Italy, Switzerland and the United States, as well as Turner and Townsend (2019), ARCADIS (2019), Comune di Milano and Regione Lombardia (2021), and Raetz et al. (2020). Equation (1) also requires the difference in labour productivity between the target and reference countries $r_{prod} = c_{prod}^{target} / c_{prod}^{reference}$*, where* c_{prod} *represents labour productivity and is computed as:*

$$c_{prod} = \frac{\text{GVA}}{\text{\# of persons employed} \times \text{average workers compensation}} \quad (2)$$

where GVA denotes the Gross Value Added to the construction sector, while the denominator is the product of the number of persons employed in the construction sector multiplied by the hourly associated worker compensation. Simply put, it represents value added per dollar spent on labour. These inputs were collected from the public databases of EUROSTAT, the OECD and the Federal Statistical Office of Switzerland. Table 1 report the inputs to Equation (1) that were used, while the resulting conversion factors were obtained equal to 1.4 for adjusting US cost data, and 2.73 for adjusting Italian cost data.

Table 1. Cost conversion function input parameters

	r_{lab}	r_{mat}	$r_{m\&p}$	f_{lab}	f_{mat}	$f_{m\&p}$	r_{prod}
USA-to-CH	0.81	1.65	1.06	0.425	0.40	0.175	0.66
ITA-to-CH	2.06	2.22	1.52	0.35	0.545	0.105	0.52

Adjustments were also made to account for inflation (e.g. the FEMA P-58 were representative of prices in 2012). Furthermore, technical/professional fees that arise on top of the operational costs of repairs are not accounted for in FEMA P-58. Previous research has shown that they can constitute up to 14% of the operational expenses (Di Ludovico et al., 2017a, b). As such, the percentage cost of technical fees added on top of our estimated repair costs was determined as 5% for DS1 and DS2, and 13% for the rest, in recognition of relevant national data on such fees reported in ETH Zurich (2015). Further details on the development of the consequence model can be found in Wiemer et al. (2023)."

All in all, I think the paper could be eventually accepted if the issues set out above were strengthened and each step specified more precisely.