Response to comments of **Anonymous Referee #1**

First of all, we appreciate the valuable comments of **Anonymous Referee #1** on the manuscript.

General responses to the comments:

1. This study is not a PSHA study

We would like to believe that the main disagreement is because the reviewer regarded our work should be like a PSHA study, which is not the case. (More explanations are followed.) It is totally understood that PSHA plays an important role in current site-specific earthquake resistant designs, from my experience working on PSHA projects and calculations for an engineering consultancy in the states, and from my recent PSHA case studies published in refereed journals.

2. Is PSHA the only solution to estimate the annual rate of earthquake ground motions?

Although PSHA is a representative method, is it necessarily the only legitimate approach for estimating the annual rate of earthquake ground motions? The answer should be clear for most researchers.

In this study, we proposed a new FOSM algorithm fort the task, one of the innovations in this study.

3. Probabilistic Analysis, Deterministic Analysis, PSHA, DSHA

The next thing we want to clarify here is the definitions of “Probabilistic Analysis,” “Deterministic Analysis,” “PSHA,” and “DSHA.”

a. Take $Y = f(X_1,...X_n)$ for example, one can find the mean value of Y given the mean values of X_is, which is referred to as the deterministic analysis.

b. In contrast, one can find both the mean and standard deviation (SD) of Y given the means and SDs of X_is, which is the so-called probabilistic analysis. But sometimes the analytical solutions are not available for such problems, so a few methods such as Monte Carlo Simulation, First-Order-Second-Moment are developed to solve it alternatively.

c. PSHA, or Probabilistic Seismic Hazard Analysis, is an analysis to estimate the annual rate of a given ground motion with a unique algorithm as shown in the following equation:

$$\lambda(Y > y^*) = \sum_{i=1}^{N_S} v_i \sum_{j=1}^{N_M} \sum_{k=1}^{N_D} \Pr\left[Y > y^* \mid m_j, d_k\right] \times \Pr\left[M = m_j\right] \times \Pr\left[D = d_k\right] \quad (1)$$

(Detailed explanations to the PSHA governing equation are skipped here and in the article because PSHA is not the focus of this study.)

d. DSHA, Deterministic Seismic Hazard Analysis, is an analysis to estimate the ground motion given a worse-case scenario in terms of earthquake size and location.

Understandably, with some details better explaining the difference between the four, one should realize that "PSHA" and "Probabilistic Analysis" are not closely related, at least in terms of the underlying algorithm.

More importantly, we like to emphasize again that our study is a Probabilistic Analysis applied to an earthquake subject, but by no means a PSHA.

4. The problem or the governing equation targeted in this study

In addition to the model error (ε_M) in magnitude conversion, we followed the idea of PSHA to also consider the uncertainties of earthquake location (*D*), size (*M*), and ground motion models (ε_G) in our analysis to estimate earthquake ground motions (*Y*). Therefore the problem can be expressed as follows:

$$Y = f(D, M, \varepsilon_M, \varepsilon_G) \quad (2)$$

After the probabilistic problem is defined, we solved it by FOSM to find the mean and SD of *Y*. With both, the probability $Y > y^*$ (denoted as $\Pr(Y > y^*)$) can be computed based on the fundamentals of probability calculations.

Next, we again followed the idea in the PSHA algorithm, so that the annual rate λ for $Y > y^*$ is calculated by adding the rate of earthquakes in the following governing equation:

$$\lambda(Y > y^*) = \lambda_{earthquake} \times \Pr(Y > y^*) \quad (3)$$

Since we can not solve the problem (i.e., Eq. 2) by extending the PSHA algorithm (Eq. 1), we made the attempt to solve it with the FOSM calculation, considering FOSM is a legitimate procedure for a probabilistic analysis with its wide applications to many subjects.

5. Summary of general response and highlights of the study

- This study is not a PSHA calculation.

- PSHA should not be the only method to estimate the annual rate of earthquake ground motions.
- The problem targeted includes four random variables, including the uncertainty of magnitude conversion that motivates this study.
- We employed FOSM to solve this probabilistic analysis, the originality and novelty of this study.

6. Writing and English

The reviewer suggested that we should make the article more clear, and we will do our very best in the revision. But for doing so, more specific comments would be more appreciated, and be more constructive. This is the purpose of the peer-review process designed for, and what we researchers are obligated to do. Comments such as "English should be heavily revised…" "I don't understand…," "It is not clear…" without specifically pointing out the technical flaws in the article are too subjective, and not being helpful and fair to authors in our humble opinion.

Specific responses to comments:

- I suggest that the organization of the manuscript will revise to point out the main aim and the results. I have found really difficult to follow a rationale among title, abstract, analysis and conclusions. Now it is not clear if the main aim is to show how the uncertainty in Mw-Ml conversion affects the hazard or to perform an evaluation at a specific site.

Response:
We will revise it to more focus on the methodology, and on the reason why we used it to estimate the annual rate of earthquake ground motions, given the influence of magnitude conversion uncertainty that is also targeted in this study.

If the aim is to account for the uncertainty (as the title suggest) I think that hazard curves should be presented along with ranges of uncertainties. If the aim is to characterize the seismic hazard at a site, a nuclear power plant, I don't think the PGA at 10% of exceedance in 50 years is the best value.

Response:
With the new FOSM calculation, the hazard curve was indeed presented in Fig. 5 in the article.

It is also noted that the case is simply an application to this FOSM calculation for a randomly selected site. We can use other sites as to demonstrate the new method.

This study is not interested in earthquake resistant designs for a specific nuclear power plant. The reason we specifically mentioned this value (i.e., 10% in 50 years) is because it is available in a benchmark PSHA study for the same site, allowing us to make a comparison between the two studies in terms of the result.

- I don't understand the use of a mean magnitude as computed in the paragraph 5. The histogram of seismicity seems to show a Gutenberg - Richter behaviour, so defining a mean magnitude is unusual. In the same manner, also the use of a mean source-to-site distance is not conventional. At the end, it is not clear if the Authors have integrated knowledge about rates of occurrence of earthquakes, the possible magnitudes and distances of those earthquakes, and the distribution of ground shaking intensity due to those earthquakes, that is the basis for any PSH study.

Response:
As mentioned, this study is not a PSHA calculation but a FOSM calculation. For any of a FOSM analysis to solve $Y = f(X_1,...X_n)$, the inputs are the mean and SD of X_is. This is simply the nature and the difference between a FOSM calculation and PSHA calculation.

Also pointed out in the manuscript, although this calculation is not following the PSHA algorithm, it targets a similar problem as expressed in **Eqs. 2 and 3**, which is exactly this comment referring to.

-The core of the methodology is distributed in three paragraphs (3,4 and 6), but it will be good to have just one paragraph describing it. Also, the spreadsheet described in Fig. 6 is not clear.

Response:
We will make it more comprehensible in the revision, and the suggestion for a better layout will be followed.

-Introduction states the aim of the paper, but the First-Order-Second-Moment (FOSM) analysis is introduced in a too short way. Please, clarify here what it is and give some references.

Reponses:
As mentioned in the general response, FOSM is a solution or approximation to a probabilistic analysis whose analytical solution is not available. Also pointed out in the manuscript, this approach is mainly on the basis of the Taylor expansion for a mathematical function, but retaining only the first-order term for completing the calculation for a probabilistic analysis of interest. In fact, this simple, novel idea proposed in the late 1960s is the backbone of FOSM.

In addition to the key algorithms of FOSM, the suggestions for more relevant FOSM contents such as applications will be followed in the revision.

-Provide an adequate geological and seismotectonic background. I think readers could benefit from this description.

Response:

The suggestion will be followed in the revision, accompanying the key scope of this paper estimating the annual rate of earthquake ground motions with a new FOSM alternative.

-In the chapter 2, and often through the manuscript, Authors describe differences between probabilistic and deterministic seismic hazard analysis, but they used an example that sounds very strange (why Authors need to cite soil's friction angles in chapter 2?).

Response:

In fact, as the title "Probabilistic Analysis and Deterministic Analysis" clearly pointed out, we referred to Probabilistic Analysis and Deterministic Analysis in this section, but not PSHA or DSHA the reviewer misunderstood. The difference between the four was given in the general response #3.

Since we aimed to explain the general difference between Probabilistic Analysis and Deterministic Analysis, we used a slope stability problem to explain it, in which one of the underlying variables governing slope stability is the soil's strength, or the friction angle in this explanation.

-Probabilistic analysis allow using all possible earthquake events and resulting ground motions, along with their associated probabilities of occurrence, in order to find the level of ground motion intensity exceeded with some tolerably low rate, so why the Authors used a single value for magnitude and distance? I know they computed their standard deviations, but figure 3 shows that magnitude ranges from 6 to 8.2, so are earthquakes with Ml larger than 6.43(+0.46) ignored?

Response:

Again, this is the underlying difference between using the PSHA algorithm and using the FOSM algorithm to estimate the annual rate of earthquake ground motions. To be more specific, PSHA reflects the uncertainty of magnitude or distance by calculating the probability density of each data bin in respective probability functions; in contrast, this

FOSM calculation, like any other FOSM analyses, reflects the uncertainties of magnitude and distance by utilizing their mean values and standard deviations.

In short, different approaches and different algorithms are the explanation to this comment.

The mean, I suppose an arithmetic mean, is guided by the boundary the Authors have chosen but, what happen if the lower threshold for Ml is 6.5?

Response:
The magnitude threshold indeed exists in this analysis, and so does in PSHA. Such a magnitude threshold is a value based on the best engineering judgment that earthquakes lower than that size should not cause damage to the structures. Like the reviewer pointing out why not 6.5, meanwhile others would challenge why not 6.0?

Understandably, some seismic hazard assessments use a logic-tree analysis to consolidate such uncertainty. But as the discussion given in Section 7.3, this study is not aimed to further discuss its influence, for making the focus more staying on the new novel ideas of this study: Using a FOSM calculation to estimate the annual rate of earthquake ground motions with the uncertainty of magnitude conversion accounted for.

-The maximum (best will be a range of) distance and magnitude should be chosen according to the ground motion predictive equation.

Response:
We do not really understand the necessity and the reason for doing so, especially when we can best estimate the values based on the input, the given observed seismicity.

Again, we understand the use of multiple maximum magnitudes in most PSHA practices with a logic tree analysis to combine the result. But this study is not a PSHA.

-The Discussion section is lacking. Here the Authors should explore the significance of their results instead, in the chapter 7, the Authors refer to a paper of Chen et al., (2007) who computed a PGA at 10% of exceedance of about 0.3g, but the following discussion is not clear. What is the novelty of their work in respect to Chen? The Authors should do some efforts to discuss improvements of their work in respect to published data in an exhaustive way.

Response:

This study and the refereed work focused on the same problem estimating the annual rate of earthquake ground motions. Understandably, the difference is that our study employed a new analytical approach, and the refereed work used a representative approach, i.e., PSHA.

The comparison shows that although two different methods adopted, the results are pretty comparable, which we considered a very exciting finding that is worth mentioning and discussing. On the other hand, based on only one case we can not make it too assertive, so that we placed such contents in Discussion and look forward to more studies to clarify this issue.

- I cannot understand what the Authors would discuss in the chapters 7.2, 7.3 and 7.4

Response:
Like more researchers, we believe that PSHA, or DSHA, or this FOSM calculation, or any other, is not scientifically perfect to the complicated, random, earthquake problem. We liked to point out such comments from other researchers to share this perspective, and to support that our FOSM analysis is logical and sound, but it is still not perfect like any others given our limited understandings of the random earthquake process.

Moreover, as researchers, we all believe that our job is to challenge existing methods (the exact comment from a reviewer for another review) and to brainstorm new innovative solutions to a problem, not simply to follow the existing ones.

Take Section 7.4 for example, to the best of our knowledge, no one can provide solid, universal evidence that earthquake location and size are indeed (statistically) independent, although this presumption is used in the PSHA algorithm and in our FOSM calculation. Our objective to make this discussion is to evoke more studies proposing new evidence to it, which in our humble opinion, will more benefit our understandings of the earthquake and enhance an analytical approach that better reflects what is really happening in the field.

- I agree that conclusions should be clear and concise, but here it is not clear if the main result is a new method or the seismic hazard at a site.

Response:
This paper focused on a new approach so it should be not too surprised to make it into the conclusion. (or what else can we do?)

On the other hand, a new method or a new application can make more contributions than many case studies combined. Just Imagine Prof. Cornell did not propose the idea of PSHA in the late 1960s.

- My last comment is that the Authors make an effort to improve the references. Many countries currently use PSHA for national building code and nuclear power plant (California, New Zealand, Italy, France, Japan…) and researcher involved in this topic produced a vast literature that is now completely ignored in the manuscript.

Response:
If this is about a PSHA study, we will do that.

Again, we know the background of PSHA that is arguably the most representative approach nowadays for seismic hazard assessment. But we suggest that the reviewer could refer to the other side of the story, such as the work by Mualchin in 2011, pointing out a few "interesting" comments why PSHA is becoming dominated.

The bottom line is: Since this study proposed an alternative to seismic hazard assessment, we referred to more relevant studies about the role seismic hazard analysis should be playing, but not to those about PSHA case studies or backgrounds, considering such a specific, analytical method is not the focus of this study.

To conclude, in my opinion the paper should be rejected in its present form, as it needs a huge effort by the Authors before a possible and deeper second round of revision.

Response:
We sincerely appreciate your valuable time reviewing this article. Some suggestions are really valuable to our revising of this article, such as more introductions to FOSM and its wide application to engineering for the reader's understandings of this analytical approach.

But on the other hand, we did not see objective technical comments on our analysis, which should be the underlying criteria for judging the merit of a scientific report, given the language is qualified for technical writing.