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Reply on RC1

Karma Tempa et al.

Author comment on "Sensitivity analysis of input ground motion on surface motion parameters in high seismic regions: a case of Bhutan Himalaya" by Karma Tempa et al., Nat. Hazards Earth Syst. Sci. Discuss., <https://doi.org/10.5194/nhess-2021-279-AC1>, 2022

Reviewer #1

General comments

This paper presents the first attempt of local seismic effects assessment in Bhutan. Considering the small amount of input data available (i.e., no instrumental records of past earthquakes, reduced geotechnical characterization of soil deposits, etc..) this study represents a first and relevant step towards a possible future deeper seismic hazard assessment. However, several critical problems need to be addressed and explained to let the manuscript be accepted for publication.

Response: We appreciate constructive comments from the reviewer. We have now assessed all the comments and we assure that all the issues raised by the reviewer will be duly addressed as follows:

Specific comments

- Introduction: This manuscript focuses on the study of seismic hazard more in particular on seismic site effects, however few lines and only one reference citation on site effects is reported in the introduction. A wider review of past studies focused on this topic needs to be integrated in the manuscript.

Response: We appreciate the constructive comment from the reviewer. We will surely present a more critical discussion on the topic referring to several works. Meanwhile, published works in the study area is currently very limited, in particular on seismic site effects. Two of the studies conducted by Tempa et al 2020 and Tempa et al 2021 which covered parametric studies and shear wave profiling to estimate the site response and these has been critically upheld to complement the current study. Some of the field investigation, or any other research and its specifics to seismic site effects will be incorporated in the revision.

- Lines 113 – 117: This sentence does not seem to be consistent with Figure 2 since the geological formations falling in the study area (black square in Figure 2) are not the same reported in the sentence.

Response: Thanks for pointing this out. We fully understand the inconsistency in the description of the geological formation of the study area. We will rectify the mistake in the revised version.

- Authors performed a reconstruction of the groundwater table in the study area considering 29 borehole data without indicating the season during which the data has been recorded. Reasonably, the groundwater table position varies during the year. An evaluation of the possibility of grouping borehole by seasons could help to refine the map, particularly in the area between Dhamdhara, Pipaldara and Kabreytar and in that close to Rinchending.

Response: Thanks for providing such insightful feedback. The investigation date is available, and it can be grouped as advised. We will do accordingly in the revised manuscript. A revised map with updated legends according to the seasons will be added where applicable.

- Lines 258 -259: “[..] low, medium, and high [...]” with respect to what? Please specify in text

Response: The authors intended to categorise the earthquake based on the level of PGA as low, medium and high in the study, so as to subsequently predict the seismic site effects as a function of amplitude parameters and deduce amplification factors. We will provide the basis for the selection of input motions and define the qualitative terms accordingly.

- Authors reported in Figure 11 the Fourier Spectra of the considering earthquake as Fourier Amplitude vs Period. It is common use to represent Fourier Spectra as Fourier amplitude vs frequency, so this representation confuses the reader. It is opinion of this reviewer that just the X label is incorrect, but please check this figure and modify it consequently.

Response: We appreciate the feedback. We will update the figure with Fourier amplitude vs frequency in the revised manuscript.

- Figure 12: This figure presents the variation of PGA induced by each earthquake at different depths in the soil. It could be more useful to present data by normalizing them to the maximum PGA of the earthquake input. Moreover, in case of Zone II the bedrock depth is fixed at 400m so Figure 12b should present data up to this depth.

Response: Thank you for the remarkable feedback. We will surely normalize the results with the max. PGA input and revise the manuscript accordingly. Also, we will plot the PGA variation up to the bedrock in both figures as suggested.

- Authors performed a series of 1D linear-equivalent numerical modelling of eight soil columns representative of the study area and reported the results in Figures 13 and 14. They showed the response spectra at bedrock and on the surface. While results obtained by applying earthquake from M1 to M4 seem to be consistent, those obtained by considering M5 and M6 look anomalous. Furthermore, in the latter case the response spectra at the bedrock level are characterized by anomalous peaks at low period that are completely nullified at the ground level. I suggest the authors to check the signal processing of these earthquakes (M5 and M6) and verify the consistency with the input applied in the numerical simulations.

Response: We appreciate the reviewer for surfacing this issue. The authors will revisit the 1D model for all the sites and check the anomalous pointed out. If necessary, the analysis results could be updated to maintain the correctness if

any. Also, we will provide a detailed discussion regarding the input motion as input strong motion characteristics may also lead to anomalies.

- All the presented results need to be more deeply discussed. Moreover, considering the shaking level of the seismic input and the typology of numerical simulation, the topic of non-linear behavior of the soil material should be addressed. This could also help for a better interpretation of the results (i.e. Figures 17 and 18)

Response: Thank you for pointing out this. We truly feel that deeper insights are required. We will thus improve the discussion section juxtaposing the results with some published works. Also, we will add insights to each result. The non-linear behavior of soils in 1D model are usually characterized by the equivalent iterative model which takes into account the strain compatibility of non-linear behavior of soils. The current study does not cover experimental nonlinearity of soils. We will also add a robust description on equivalent linear and fully nonlinear soil behavior in the revised manuscript.

Technical correction

- Line 24 -26: This sentence is not clear

Response: We will rewrite the sentence.

- Line 86: Please specify which site effect you are investigating

Response: The current study in particular draws site effect in terms of amplification factor attributed mainly due to input motion amplitude parameters. To determine the amplification factor at the end, the spectral acceleration of surface and bedrock has been provided prior basis. The details will be discussed in the revision.

- Line 186: This sentence is not correct.

Response: We will correct the sentence accordingly.

- Line 189: This in-text citation is not present in the reference list

Response: We will cross-check text and reference sections in the revised manuscript.

- Lines 359 - 360: This sentence is not clear.

Response: We will rewrite the sentence in the revised version.

- Line 396 – 398: This sentence is not clear.

Response: We will update the sentence in the revised manuscript.

- Are Baxa (Figure 2) and Buxa (Line 113) the same lithological group?

Response: Buxa is correct lithological group. We will update accordingly in Fig. 2.

- Table 1: What "-do-" stands for?

Response: The authors intend to indicate same test methods in Dhamdhara and Rinchending. The “-do-” will be removed and replaced with the test methods in the revised version.

- Figures 1b: The legend is missed

Response: The Legend will be modified properly.

- Figure 2: Please add the location of boreholes reported in Figure 5. Moreover, north direction and scale are missed.

Response: Borehole locations can be added with north and scale and Figure 2 will be updated.

- Line 173 – 175: Acronyms should be explicitly reported in the manuscript.

Response: The acronyms will be reported in the revision.

- Line 195-197. This sentence about liquefaction and corresponding potential is out of the paper topic. Please delete it.

Response: The sentence concerning liquefaction will be deleted as advised.

- Figure 3: The legend is not clearly legible

Response: The legends of the Figure 3 will be modified.

- Figure 7: The resolution of this figure is too low

Response: The Figure 7 has been used from a government report. We will recreate the figure in the revised manuscript.

- Figure 10 – 11: To improve the manuscript readability, these figures could be merged in a unique figure composed of two columns, one devoted to time histories and another to the corresponding FFT spectra.

Response: The Figures 10-11 will be merged and presented in two columns or consolidated two figures.

- Figure 12: Colors chosen for Earthquakes M4, M5 and M6 are too similar. Please use more distinguishable colors

Response: For Figure 12, contrasting color scheme will be implemented.

- Figure 13: Please add “bedrock” and “ground surface” as labels in the graph

Response: The labels in Figure 13 will be changed to “bedrock” and “ground surface” in the revision as advised.

- Figures 15 -16: Please specify how you calculated the red line FFT. Is it an average of the FFT values at each time step? Please specify in the text.

Response: The red line illustrated in the graph is an average value. The specification can be done either in the graph or in-text during the revision. We will add description regarding this in the revised version.

- Figure 17b/d – 18b/d: How have you calculated the “Response spectrum intensity” and “Mean frequency”? Please specify in the text

Response: We will present the results as suggested by the reviewer in the revised manuscript.

- All the figure’s caption should be improved

Response: As advised, the authors will re-visit the figure captions as a whole and make sure that they are appropriately described.

- In-text citations need to be modified according to the journal guidelines.

Response: The authors will check according to the Journal’s guideline for submission and update it in the revision.

Thank you.