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| ***Manuscript Number:*** | *ENGEO\_2019\_1117* |
| ***Title (new):*** | *ASSESSING THE SPATIAL VARIABILITY OF GROUND MOTION FOR MICROZONATION PURPOSES: THE CASE STUDY OF CAVEZZO MUNICIPALITY (ITALY)* |
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**Introduction to Review Reply**

*The authors would like to express a word of appreciation to both Reviewers for the efforts and the time invested in reviewing their manuscript. The proposed suggestions and constructive criticism will help to improve the overall quality of the submission.*

*Hereinafter, the authors provide a reply to the comments of the Reviewers. All critical matters have been considered and, whenever possible, fixed. Major modifications have been highlighted in red in the manuscript, to facilitate the Reviewer’s counter-check.*

**Comments to Reviewer #1**

The Paper ENGEO\_2019\_1117 presents the approach adopted to characterize the seismic response of a village at level III microzonation within the LIQUEFACT project. The topic is conventional, but the Authors collected a large amount of data. It cannot be published in the present state due to some drawbacks, which should be handled by the Authors to improve the overall quality of the paper. The amount of collected data should be emphasized together with a more critical discussion of some of the made choices.

*R: We thank the Reviewer for his suggestions, which were certainly essential to improve the overall quality of our manuscript. A detailed review reply is provided separately for each identified issue.*

1. **TITLE**
   1. I was not able to identify the multi-scale in this paper, as only the Cavezzo village is analysed. I suggest to remove from the title.

*R: The definition of multi-scale was introduced in the title to highlight the different spatial resolution of the geophysical techniques used during this investigation and also the various scales at which geologists, seismologists and geotechnical engineers operated to define their corresponding models. The challenge of this work was defining a unified subsoil model of an urban centre that is compatible at all the scales at which it has been studied.*

1. **INTRODUCTION**
   1. It is quite limited, as most of it is occupied by the description of the LIQUEFACT project. I suggest to improve it focusing on a brief-state-of art on the topic and discussing the open issues.

*R: As suggested by the Reviewer, the authors re-edited large parts of the Introduction. Studies available in the literature on the seismic microzonation for ground shaking have been added and discussed in the new version of the Introduction.*

* 1. Several national and international papers deal with III level microzonation, some of the most recent should be cited.

*R: As suggested by the Reviewer, a brief-state-of art, including national and international references on the topic under investigation, has been added in the new version of the Introduction.*

* 1. The explanation of the Project should be reduced, the description of the other modelled sites is not necessary.

*R: As suggested by the Reviewer, the explanation of the Project was reduced and the description of the other case studies was removed from the manuscript.*

* 1. Emilia earthquake was studied by several Authors both as seismic sequence and for the liquefaction occurrence, some reference are mandatory.

*R: We added some relevant references to the manuscript.*

1. **GEOLOGICAL AND SEISMOTECTONIC SETTING**
   1. It is sufficiently synthetic and informative, but I think some reference on the buried structural setting are necessary.

*R: A few relevant references has been added to the manuscript.*

* 1. A geological cross-section of the study area is necessary.

*R: A new map with geographical location of the study area and a geological cross section has now been included.*

1. **METHODOLOGY**
   1. The methodology is a difficult to follow, I suggest to summarize it, through bullet points.

*R: We have rewritten the description of the methodology and reorganized in major bullet points.*

1. **GROUND CHARACTERIZATION DATASET**
   1. The dataset is made of a large amount of tests and data. I suggest to provide a synthetic table with all the relevant information in order to better highlight the high number of data.

*R: As suggested by the Reviewer, a new table (Table 1) including the type and number of geotechnical and geophysical tests adopted for ground characterization of the territory of Cavezzo, was added in the manuscript.*

* 1. The sentence on INGV and OGS is not necessary, it could be moved in the Acknowledgments.

*R: The authors have modified the sentence in the manuscript to clarify the role played by INGV and OGS in the ground characterization of Cavezzo territory avoiding phrasing adopted in the Acknowledgments. Researchers from INGV and OGS are co-authors of this paper so the authors believe that there is no need to mention INGV and OGS in the Acknowledgments. On the other hand, this sentence is necessary to introduce the origin of two complementary velocity profiles discussed in the following Sections of the manuscript.*

1. **MODELING OF THE SUBSOIL**
   1. It is not properly clear how MOPS were identified. Further details should be provided, together with typical stratigraphic logs. Aren't 9 MOPS too much for a small area as the analyzed one? Is the geology so heterogeneous?

*R: The MOPS have been identified using an approach described in detail in the work introduced by Meisina et al. 2019, which includes also the typical stratigraphic logs for each MOPS. In the opinion of the authors, a detailed description of such approach is beyond the scope of this summary work and we refer to the aforementioned paper for further details.*

* 1. Is the seismic bedrock represented by the Blue Clays? Please state it clearly.

*R: Blue Clays are indicated in literature as geological bedrock, which however do not necessarily represent the geophysical (seismic) bedrock, where the fundamental resonance mode is supposed to develop. The term “geological” has then been added to the manuscript to avoid misinterpretation.*

* 1. The Authors should consider to discuss the results of their soil characterization with this VS30 map of Italy produced by other Italian authors: <https://www.sciencedirect.com/science/article/pii/S0267726118311114>

*R: The work done by Forte et al. 2019 is certainly interesting. Nonetheless, the referenced work is in the opinion of the authors is meaningful for those analyses requiring a robust -although coarse- soil classification over very large territories such as the case for PSHA at national level. Such approach is incompatible with the level of detail required by the proposed investigation. It is to mention that, although a reasonable matching of the Vs30 value has been found by the authors, the latter think that presenting and discussing such comparison would not be pertinent.*

*We nonetheless appreciate point raised by the Reviewer. We will further investigate it in a separate work presently ongoing for the Friuli region.*

* 1. Please provide a more critical discussion on the use of 1d-linear equivalent approach, because its use could be questionable and the results inaccurate, in particular due to layer geometry and close hypocentral distance earthquakes.

*R: Two-dimensional linear-equivalent ground response analyses were carried out with reference to two representative vertical cross-sections using QUAD4M (Hudson et al., 1994). From the comparison of the results from 1D and 2D ground response analyses, it was inferred that for the frequencies of interest in the microzonation study, 2D effects are negligible. A few sentences are included in the manuscript on this issue.*

*Concerning the limits of the linear-equivalent constitutive model for the soil, the authors think that they have been thoroughly discussed in Section 8.*

*Finally, the reference seismic hazard at the site was defined according to the probabilistic framework, as specified by the current Italian building code (NTC, 2018), for three return periods (475, 975 and 2475 years).*

1. **RESULTS**
   1. Few sentences on the choice of using these parameters to characterize the amplification should be added.

*R: The amplification factors have been computed following the prescriptions of the Emilia Romagna guidelines (2015, DGR n.2193), which have been better referenced in the paper.*

1. **DISCUSSION AND CONCLUSIONS**
   1. Some consideration on the areas where liquefaction occurred and the value of seismic acceleration or amplification in the same could be very interesting.

*R: As suggested by the Reviewer, a reference to the areas where liquefaction phenomena were observed in during the 2012 seismic sequence has been added. At least, for these sites, the linear-equivalent approach adopted in this study is inadequate. Advanced ground response analyses are required. These types of analyses are currently ongoing.*

1. **FIGURES**
   1. The symbols for the fluvial elements are very similar and confusing. Try to differentiate more, i.e. ridge less and more than 2m. The DEM resolution is not clear, use the higher resolution (as in fig. 2) or insert contour lines.

*R: [CLAUDIA] Full resolution pictures will be uploaded in the final version of the manuscript.*

* 1. Fig. 2 is filled with information, you could consider to produce n. subfigure for each kind of investigation.

*R: Information in Figure 2 (now Figure 3) has been redistributed in 3 consecutive plots, to facilitate the reader to distinguish between pre-existing and newly-made investigations from different sources.*

**Comments to Reviewer #2**

This manuscript presents a summary of the research activities on seismic microzonation of Cavezzo municipality. Authors apply a multidisciplinary approach to estimate pseudo 3D seismic velocity model under the municipality and utilize for amplification factors. Author mention broad range of methods and results. In general, I feel that the topic of the paper is interesting and should be of interest to readers of Engineering Geology. My modest criticism is that the manuscript reads rather as an overview of a project, not as regular research paper. The development of the 3D model is insufficiently described, the descriptions do not go into detail. It would be difficult for interested readers to apply suggested procedures. The transferable “lessons learned” should be presented as well. Therefore, I recommend a revision of the manuscript. Authors should focus on more detailed descriptions of the new significant approaches. They should clearly specify what are inputs (and outputs) of the current study, and cite papers or reports which include details on these inputs (velocity models, results of MASW, electric tomography …).

*R: We would like to thank the Reviewer for the appreciation to our work. We agree that some sections were insufficiently detailed, while other sections were filled with project details not necessarily useful or interesting for the reader. We have revised the manuscript accordingly.*

**Specific comments:**

1. Title is too long and not very attractive.

*R: The Authors consider the information in the title necessary to highlight the different spatial resolution of the geophysical techniques used during this investigation and also the various scales at which geologists, seismologists and geotechnical engineers operated to define their corresponding models.*

1. Abstract should be rewritten, it is too general and reads rather as an introduction and not the summary of the paper. It should be focused on specific scientific objectives and results.

*R: The abstract has been rewritten and now it focuses on the key topics of the presented work.*

1. The development of 1D seismo-stratigraphic profiles should be described in more detail – an example in the manuscript would be helpful.

*R: The section about the seismo-stratigraphic model has been rewritten and extended, providing more details on the definition of the velocity model. It must be noted that new figures are also provided, presenting the latest version of the inverted velocity models.*

1. How the OGS model compares with measured H/V? Is the velocity jump present in the INGV model necessary to fit observed H/V?

*R: As it is now better described in the Section about the construction of the seismo-stratigraphic model, the INGV model (now renamed to EUCENTRE) is constrained by the combined used of dispersion (L+R), ellipticity (R) and f0 (this last coming directly from H/V analysis). The model therefore compares well to H/V ratio in the low frequency range, where a good match between H/V and Rayleigh ellipticity is generally expected (the “right flank” of the curve). For the benefit of the Reviewer, it is here provided a comparison of the modelled ellipticity (coloured lines) versus mean H/V at the centre of the array (scaled by square root of 2).*



*To answer the original Reviewer question, the jump in the profile is then necessary to fit the ellipticity information for the INGV-EUCENTRE model (which is indeed inverted using the ellipticity), while the OGS model (from reflection seismic) produces a similar frequency peak, but of less comparable amplitude. This might be due to the lower contrast of impedance (perhaps not fully resolved by reflection seismic), but also to other balancing effects such as intrinsic attenuation. Nonetheless, both two models explain reasonably well the observed surface wave data (e.g. figure 7), and are therefore considered equally reliable and used complementary for the subsequent analysis. This is now better stressed in the manuscript.*

*It must be noted that a separate publication by the same authors where the performances of active and passive methods are more critically compared and analysed is under development.*

1. Page2: “The resolution scale in grade 1 microzonation is low.” Please be more specific.

*R: The sentence was removed from the manuscript since it is a repetition indicating that grade 1 is a basic level of microzonation.*

1. Section 5.3: “For that, a map of the surface Rayleigh wave velocity variability was first obtained by interpolating the VS30 estimates from 83 MASW analyses (Figure 6).” It is not very clear what has been done? Do you mean shear wave velocity instead of Rayleigh wave velocity?

*R: The sentence has been corrected to: “To constraint the shallow portion of the velocity model, a map of the Vs30 variability was first obtained from existing MASW analyses from 83 previous surveys”. Moreover, additional explanation of the methodology has been added to the end of the section.*

1. Section 5.3: “Spatial interpolation of the VS30 values was performed using Geostatistics” Geostatiscs is name of a software? Please specify.

*R: The sentence has been reformulated to “Spatial interpolation of the VS30 values was subsequently performed using widely used geostatistic algorithm, i.e. ordinary Kriging (Isaaks and Srivastava, 1989).”*

1. Section 5.5: The details on soil samples tested in laboratory are not presented at all (material type etc.). The Figure 7 has no meaning in this way. Is this sample representative for the entire area? Please comment in the text.

*R: As suggested by the Reviewer (see point 15), we removed the figure and re-wrote the description in Section 5.3 on the equivalent-linear approach adopted to carry out ground response analysis.*

1. The amplification map should be briefly discussed (what is exactly the origin of the ground motion variability etc.).

*R: The discussion of the results in terms of amplification maps have been enriched in the new version of the manuscript.*

1. The quality factors are not discussed in the paper at all.

*R: An equivalent-linear approach has been adopted to approximate the non-linear, inelastic behaviour of soils. The discussion of this issue has been enriched in Section 5.3 of the new version of the manuscript.*

1. Figure 1: Coordinate system (datum & grid) is not specified. Contours might better represent terrain as the colour scale interferes other features in the map.

*R: Figure has been modified according to suggestion.*

1. Figure 2: Same as for Figure 1, contours might better represent terrain as colourful scale interferes other features in the map. Moreover, colour scale used for DTM differs from the one used in Figure 1.

*R: Figure has been modified according to suggestion.*

1. Figure 3: Zone characteristics are not presented in the text. It is then impossible to understand the final results presented in Figure 8.

*R: Zone characteristics are described in detail in the work introduced by Meisina et al. 2019. In the opinion of the authors, a detailed description of such approach is beyond the scope of this summary work and we refer to the aforementioned paper for further details*

1. Figure 4 is difficult to read, it is not specified what it shows. The variability of the top layers is not visible. Colour coding is not presented.

*R: New 2D plots have been included instead, better presenting the shallower velocity distribution and the geometry of the reconstructed seismic bedrock.*

1. Figure 7: remove, see my comment above.

*R: The figure has been removed in the new version of the manuscript.*