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Interactive comment on "ER3D: a structural and geophysical 3D model of central Emilia-Romagna (Northern Italy) for numerical simulation of earthquake ground motion" *by* Peter Klin et al.

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The authors kindly thank the anonymous Reviewer for the comments on their manuscript. In the following the authors provide the answer to each remark and illustrate the corresponding changes that were applied to the manuscript.

Reviewer's remark (1)

Introduction, pg. 2, line 9-10: deviations of ground motion observations from empirical predictions are typically obtained in the near source region of large earthquakes or in complex geologic conditions (e.g. deep basins), because the GMPEs are poorly

calibrated and/or are not properly parameterized to account for those effects. Authors should specify better the reasons for the inconsistencies between GMPEs and recordings.

Authors' answer:

We agree on specifying better the reasons for the inconsistencies. Therefore we substituted the sentence "Those deviations are usually due to physical phenomena that in principle can be taken into account by using the numerical-deterministic method. " on pg.2, line 10 with the following: "Those deviations imply the presence of case-specific features in wave generation or propagation (e.g., complex fault ruptures, complex geological structures, such as deep basins), which are not adequately considered in the derivation of the GMPE. In order to predict the effects of these features we may apply numerical-deterministic methods".

Reviewer's remark (2)

Introduction, pg. 2, line 29-30: with reference to Paolucci et al. (2015), the satisfactory agreement between simulated and recorded motions was not only due to the modelling of the extended seismic source but also to that of the most significant geologic discontinuities. The latter were demonstrated to be critical to explain the propagation of surface waves towards North and South.

Authors' answer:

The reviewer is right, therefore we substituted the sentence "The overall satisfactory agreement of their simulated waveforms with the empirical records was however attributed principally to the assumed extended source model (i.e. slip distribution and rupture propagation) rather than to their model structure, which contains only two main geologic interfaces." with the following one: "The overall satisfactory agreement of their simulated waveforms with the empirical records is due to two key-elements: the extended source model (i. e. slip distribution and rupture propagation) and the 3D structural model, which contains only two main geologic interfaces, (i. e. the base of the Pliocene formation and that of the Quaternary deposits). In particular, the satisfactory simulation of the surface waves trains stems mainly from the shape of the interface of the base of the Quaternary deposits."

Reviewer's remark (3)

Four references are missing: Guillen et al., 2004; Lajaunie et al., 1997; Chiles et al., 2004; Chiles et al., 2006.

Authors' answer: We removed the erroneous citation Chiles et al., 2006 and added the following items to the list of references:

Chiles, J.P., Aug, C., Guillen, A., and Lees, T., 2004, Modelling the Geometry of Geological Units and its Uncertainty in 3D From Structural Data: The Potential-Field Method: Proceedings of "Orebody Modelling and Strategic Mine Planning", Perth, WA, 22 - 24 November 2004, AusIMM, 313-320.

Guillen, A., Courrioux, G., Calcagno, P., Lane, R., Lees, T., and McInerney, P., 2004, Constrained gravity 3D litho- inversion applied to Broken Hill: Extended Abstract, ASEG 17th Geophysical Conference and Exhibition, August 2004, Sydney.

Lajaunie, C., Courrioux, G., Manuel, L., (1997): Foliation fields and 3D cartography in geology: Principles of a method based on potential interpolation. Mathematical Geology 29 (4), 571-584.

In consideration of the changes requested by the other Reviewer, the following reference was added as well: Calcagno, P., Chilès, J.-P., Courrioux, G., Guillen, A., (2008): Geological modelling from field data and geological knowledge: Part I. Modelling method coupling 3D potential-field interpolation and geological rules: Recent Advances in Computational Geodynamics: Theory, Numerics and Applications. Physics of the Earth and Planetary Interiors 171 (1-4), 147-157.

Reviewer's remark (4)

Section 2.3: I suggest the authors to improve the description on how the elastodynamic properties of the soils were defined. Authors provide the basic relationships between Vp-Vs, Qs-Vs and Vp as a function of depth, but further details on how these functions were calibrated should be provided (which data? References?). Furthermore, in Table 1 values of Vs and Qs should be also provided besides Vp and its gradient, as they are fundamental (more than Vp) for any site response model. How does the Vs velocity model proposed by the authors compare with the ones available from geophysical surveys in the (e.g. Milana et al. 2014)?

Authors' answer:

Following the Reviewer's suggestion, we improved the description of the elastodynamic properties. To this aim, we substituted the line "found by Brocher (2005) for VS and the relation: " after equation (1) with the following text:

"that was found by Brocher (2005) from a large number of measurements made in a variety of lithologies including Quaternary alluvium and Miocene sedimentary rocks, which constitute a fundamental part of our model. We also adopted the well established relation (eq.2 follows)"

At the end of the section we added the following discussion:

"We tested the validity of eq. (1) by analyzing the consistency of the predicted Vs with some measures of Vs resulting from geophysical surveys performed in the Po plain. According to eq. (1), the value Vp=1.5 km/s assigned to the uppermost formation A (table 1) - having a thickness of the order of 100m on most part of the area – turns out in Vs=0.34 km/s. This value is compatible with the average value found for Vs with ESAC method by Priolo et al. (2012) at three different sites of the Po Plain in a similar formation down to a depth of 120 m. At larger depths the proposed geological model presents significant lateral heterogeneities and could not be directly compared with the existing 1D Vs profiles that were derived from surface waves' dispersion by Malagnini et al. (2012) and Milana et al. (2014) in the frequency bands of 0.083-0.33

Hz and 0.15–0.70Hz, respectively. For example, in the depth range between 2 and 4 km our model features the simultaneous presence of very different formations, such as the Miocene and Late Messinian-Early Pliocene formations (M and MP, respectively, with Vs in the order of 1.7 km/s) and the Carbonatic succession (Ca, with Vs velocity as high as 3.3 km/s). On the other hand, the two "empirical" 1D velocity structures previously cited feature velocities between Vs=2.0 km/s and Vs=2.5 km/s within the same depth range, which are compatible with the average value of the Vs values found in our model."

We added the following items to the references:

E. Priolo, M. Romanelli, C. Barnaba, M. Mucciarelli, G. Laurenzano, L. Dall'Olio, N. Abu Zeid, R. Caputo, G. Santarato, L. Vignola, C. Lizza and P. Di Bartolomeo (2012): The Ferrara thrust earthquakes of May-June 2012: preliminary site response analysis at the sites of the OGS temporary network. Annals of Geophysics, 55, 4 ; doi: 10.4401/ag-6172

G. Milana, P. Bordoni, F. Cara, G. Di Giulio, S. Hailemikael, A. Rovelli (2014): 1D velocity structure of the Po River plain (Northern Italy) assessed by combining strong motion and ambient noise data. Bull. Earth. Eng., 12, 2195–2209.

Moreover, we added a column with Vs, Qs, density and Qk values in table 1, as suggested by both Reviewers.

Reviewer's remark (5)

Section 4.3: referring to Fig. 8, are the horizontal PGV values? Geometric mean or maximum of horizontal components of ground motion? What about vertical component? From Fig. 8, it is noted that at very short epicentral distances, typically less than 5 km, PGV from recordings are higher than the simulated ones, for both events. Furthermore, I encourage the authors to extend the comparison between recordings and synthetics by showing for selected stations a clearer comparison in terms of velocity

waveforms and corresponding Fourier amplitude spectra (at least for some components of ground motion).

Authors' answer: In order to answer to the Reviewer's remarks we made the following changes:

a) we substituted the first sentence in the caption of Fig. 8 with the following one: "Peak ground velocity (PGV, peak value of the two horizontal components) at the considered stations as a function of the epicentral distance."

b) in paragraph 4.2, on page 8, after the sentence "We compared the simulated ground motion with the empirical one in terms of horizontal peak ground velocity (PGV) defined as the peak modulus of the vector sum of the two horizontal components and in the duration defined as the time interval length between 5% and 95% of the Arias intensity (Arias, 1970)." we added the following text: "The vertical component was excluded from this comparison since it was systematically lower than the horizontal ones.".

c) in paragraph 4.2, on page 8, in the discussion regarding Fig. 8 after the final sequence "The high variability shown by stations at similar epicentral distance is probably due to the different source-station azimuth and focal mechanism-radiation pattern." we added the following sentence:

"As observed in Maufroy et al (2015), the uncertainty in source characteristics may impact the numerical predictions especially at short distances. The remarkable underestimation of PGV for the event 2 at station T800, located just above the hypocenter is therefore not too surprising and could be attributed to the combined effect of inaccurate hypocentral location, focal mechanism, and near-source heterogeneities. In fact, considering that source 2 has a dip of 33° (Table 2), T800 is near to the P-wave radiation maximum and at the margin of the S-wave lobe. Figure 10 confirms this interpretation: the simulated seismogram features a pronounced P-wave amplitude in the vertical component, if compared to the S-wave one. On the other hand, in the same Figure 10, the recorded seismogram presents a reversed picture: the relatively weak

P-wave (smaller than the simulated one) and strong S-wave indicate that the actual source characteristics are different from what we assumed. "

d) we changed figure 10 with a plot showing a clearer comparison in terms of waveforms, including vertical components as well as Fourier amplitude spectra. In order to support the explanation of the discrepancy in the amplitudes at station T800 we also added waveform comparisons related to the event 2.

Editorial typos

Pg. 3, line 24: Boccalletti et al. 20111 - Eq. (3): specify that Vs is expressed in km/s - Pg. 7, line 10: Moczo et al. (2002) - Pg. 8, line 10: remove "t" at the end of the line - Table 2: add rows for Vs and Qs, as commented above, and change Vp to Vp(z=0).

Authors' answer: Corrected

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