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Comment on “Implications of surface wave data measurement uncertainty on seismic ground response analysis” by Jakka et al.

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Short title: Comment on “Implications of surface wave data measurement uncertainty on 1D seismic GRA”

Comment on “Implications of surface wave data measurement uncertainty on seismic
Ground response analysis”

By Comina and Foti

Abstract

We discuss a paper dealing with the effect of shear wave velocity uncertainties on 1D seismic ground response analysis. In particular, the paper refers to uncertainties deriving from the solution of the inverse problem in surface wave methods. We address some issues related to the evaluation of “equivalent” profiles from surface wave data, the inversion strategy and the numerical simulation of seismic site response. The pitfalls in the analyses point out the need for more refined studies to draw general conclusions on the subject.

Discussion

Jakka *et al.* [1] (in the following called “the Authors”) studied the implications of surface wave data measurement uncertainty on the seismic response of a soil column. The Authors claim that the uncertainty propagation may lead to erroneous estimates of site response parameters and consequently to erroneous design of engineering structures.

The Authors refer to a previous study by Foti *et al.* [2] in which it was conversely shown that, with a reliable consideration of experimental uncertainties, the impact of solution non-uniqueness on seismic response simulations was negligible for the considered examples (i.e. “equivalent” profiles from the surface wave data inversion were also “equivalent” for seismic ground response analyses). Foti *et al.* [2] stated that no general conclusion could be drawn from few examples, but the proposed methodology could be considered a useful tool for the assessment of uncertainties caused by solution non-uniqueness. Nevertheless it is of paramount importance that the problem is correctly posed and addressed with rigorous methods of analysis.

The Authors also refer to two other studies on the same topic: (i) Boaga *et al.* [3] claimed that, in the case of a gradual velocity increase with depth, solution non-uniqueness affects the reliability of seismic response analyses; (ii) Roy *et al.* [4] reported large variability in site amplification with a similar approach. The Authors however do not refer to two other contributions (Socco *et al.* [5] and Pettiti *et al.* [6]), which discussed some serious pitfalls in the analyses by Boaga *et al.* [3] and Roy *et al.* [4]. Particularly in Socco *et al.* [5], it is highlighted the importance of: (i) a reliable estimation of experimental uncertainties in the dispersion curve; (ii) a proper misfit-based selection of "equivalent" profiles; (iii) a rigorous procedure for ground response analysis.

As for the first item, Jakka *et al.* [1] performed a statistical evaluation of measurement uncertainty observing a decrease in uncertainty (decrease in CoV) in the experimental dispersion curve going from low to high frequencies, consistently with previous studies [7,8]. They adopted the empirical formula proposed by Boaga *et al.* [3] to fit the observed uncertainty. Socco *et al.* [5] already discussed the inconsistency of this formula in the low frequency range.

In the present discussion, we focus our attention on the following issues: (1) what has to be considered “equivalent” in the surface wave inversion and the way this inversion has to be performed; (2) the correct approach to seismic ground response simulations.

For one, it is not clear how the Authors selected “equivalent” profiles. Indeed they state that “After the inversion, as it is a tedious work to consider all the profiles for 1D ground response analysis, 60 equivalent profiles have been selected covering the whole misfit band”. In our opinion, the number of profiles should not be selected on the basis of the tediousness of the work but on the basis of quantitative criteria, e.g. their relative misfit with the experimental dispersion curve. There is no indication of the fitting priority of the 60 selected profiles in [1] and the statement “covering the whole misfit band” is very qualitative. In Fig. 1 we have superimposed the experimental dispersion curve of the Author’s site 1 (LBS ground site in IIT Roorkee campus, Figure 4 in [1]) with uncertainty bounds and what the Authors claim to be “the 60 selected equivalent dispersion curves” (Figure 7a in [1]). Some of the theoretical dispersion curves fall largely outside the uncertainty bounds that the Authors have calculated; hence the corresponding profiles cannot be considered reliable solutions of the inverse problem.

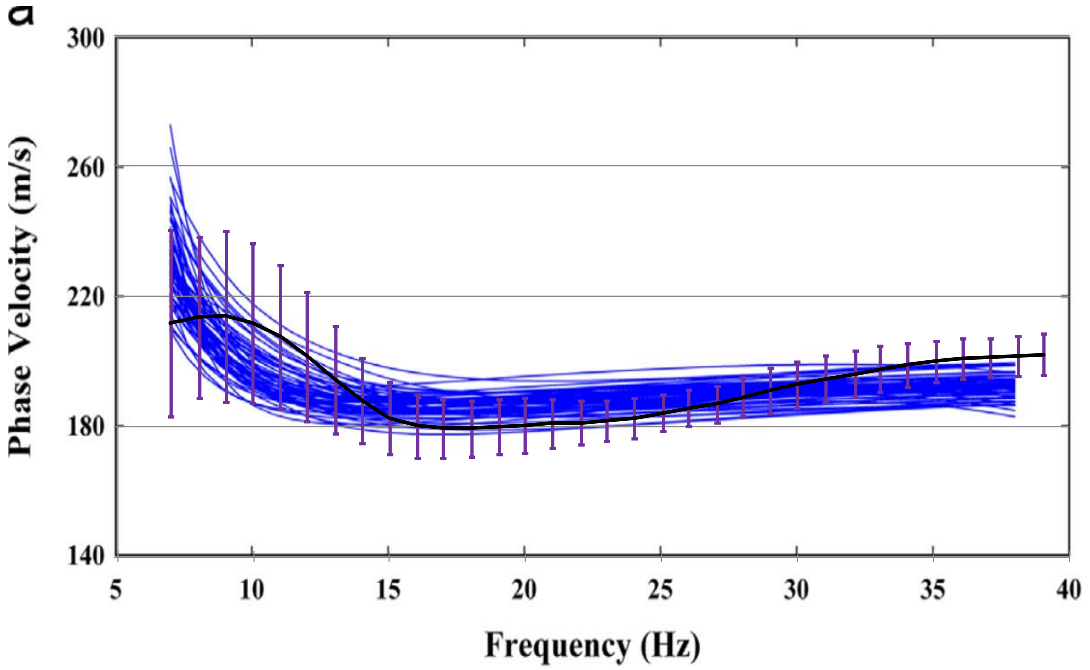

Figure 1 – Mean experimental dispersion curve with standard deviation for site 1 (fig. 4 in [1]) superimposed to the theoretical dispersion curves for the shear wave velocity profiles selected for the ground response analysis (fig. 7a in [1]).

Moreover the available information in the experimental dispersion curves covers a very narrow frequency range. In particular for site 1 the longest available wavelength in the experimental dispersion curve is about 30m. A rough but widely accepted rule states that the investigation depth is about half the longest available wavelength in the experimental dataset [e.g. 9, 10 and 11], hence about 15m in this specific case. Below this depth, there is no sufficient information to constrain the solution and a very wide range of variability has to be expected for the shear wave velocity profile [12]. This is the case in the solutions reported by the Authors (Figure 7b in [1]), in which the lack of constraints makes the shear wave velocity of the bottom layer (what they call the “half space”) highly variable. Also the Authors have mentioned this issue: “the half space is having the maximum variation of velocity”. It should have warned them that the considered investigation depth was not appropriate. This issue cannot be considered a problem of non-uniqueness in “equivalent” profiles, but rather it is a pitfall in the interpretation procedure adopted by the Authors. Same considerations apply also to the second dataset in which a similar investigation depth is obtained.

Another main issue is related to the influence of higher modes of propagation. In the interpretation provided by the Authors, the experimental dispersion curve has been associated to the fundamental Rayleigh mode. Such approach is reasonable only in simple stratigraphic conditions, while it may lead to gross errors in more complex situations where higher modes play an important role in the propagation [9 and 13].

In particular for Site 1 of [1] the increase of phase velocity at high frequencies (Figure 1) can be attributed to the presence of a stiff top layer, as also confirmed by a-priori information on the soil stratigraphy [1]. In such stratigraphic conditions, higher modes govern energy propagation in the high frequency range; hence the use of a multimodal approach for the inversion is widely recommended [14, 15 and 16]. Neglecting higher modes is likely the reason for which selected solutions by the Authors tend to lie below the experimental curve in the high frequency range (see Figure 1).

To evaluate a set of “equivalent” profiles using a consistent framework we have then inverted the dispersion curve of the Author’s Site 1 with the multimodal Monte Carlo inversion algorithm proposed by Maraschini and Foti ([17]). For the Monte Carlo inversion, 10^5 simulations have been performed. Equivalent profiles have been selected on the basis of the statistically based procedure adopted by Foti *et al.* [2]. Figure 2 shows the set of selected equivalent models and relative dispersion curves. A representation based on the misfit is adopted, for both dispersion curves and corresponding velocity profiles: the transition from dark to light colours reflects the passage from low to high misfits on the dispersion curves.

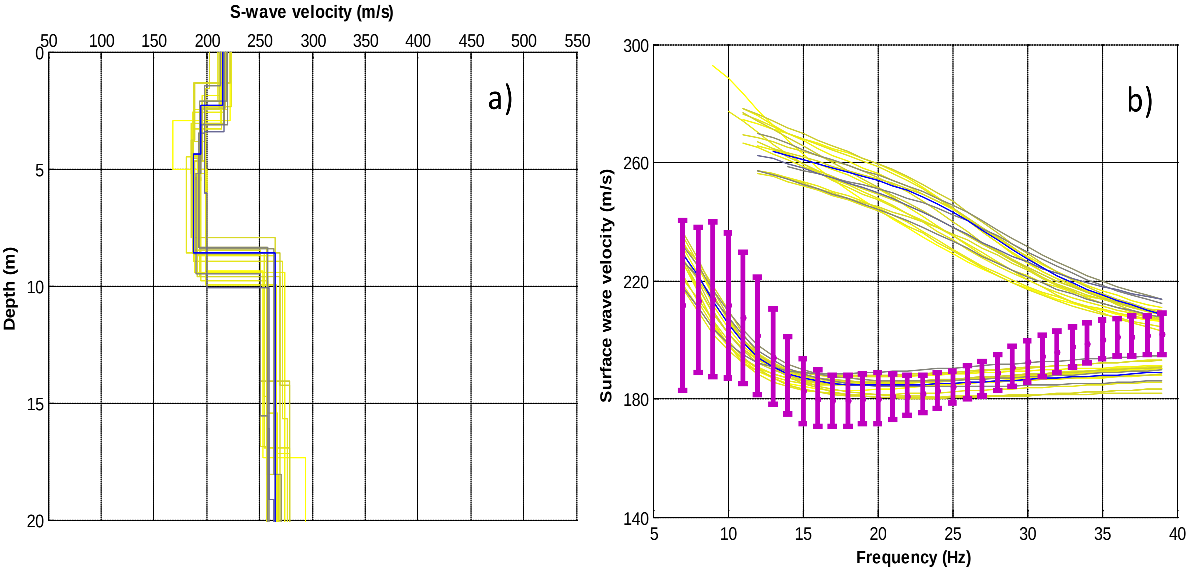

Figure 2 – Dispersion curve of Site 1 (Fig. 4 in [1]) inverted with the multimodal approach of Maraschini and Foti [17]: (a) selected equivalent profiles; (b) experimental dispersion curve (thick error bars) and theoretical dispersion curves corresponding to selected models. The colour of each theoretical dispersion curve is the same as of the corresponding shear wave velocity profile.

Coherently with the expectations, in the high frequency range a clear transition to the first higher mode is observed (Figure 2b). Moreover the set of "equivalent" profiles (Figure 2a) is very different and much narrower than the one proposed by the Authors (Figure 7a in [1]), showing also a reduced variability. Profiles associated to a bad fitting of experimental data (light colours in Figure 2) are to be considered less reliable. Such information is missing in the Author representation. It can be also noticed that the inverted profiles better matches the a-priori stratigraphic information [1]. Given the reduced variability of this new set of "equivalent" profiles, we are confident that the uncertainty in amplification and response spectra would be much less than those obtained by the Authors and comparable to those reported by Foti *et al.* [2], Socco *et al.* [5] and Pettiti *et al.* [6].

Concerning the numerical simulation of the seismic ground response performed by the Authors, Pettiti *et al.* [6] already discussed it with several arguments. In particular the application of the input motion to soft materials, as those at the bottom of both Authors’ sets of profiles [1], would require a deconvolution procedure [18], which is not specified in their paper. For the deconvolution it would be necessary to know the depth of the seismic bedrock and the Authors do not address this issue. As an example, for their site 1 what they claim to be the “half space” is a “fine sand” layer and not a stiff bedrock. Moreover, as discussed above, the position and velocity of this last interface falls well below the limit of a reasonable investigation depth and consequently it shows high variability in the retrieved shear wave velocity profile. This variability strongly affects the numerical simulations results and cannot be associated to surface wave uncertainty but rather to a pitfall in the inversion process. In real cases, if the investigation depth of surface waves does not reach the seismic bedrock, this information should be introduced into the process as an a priori information from other surveys (e.g. seismic reflection/refraction) as done for instance by Foti *et al.* [2].

Conclusions

We can conclude that the discrepancy in spectral parameters observed by the Authors is not related to surface wave inversion non-uniqueness but to some pitfalls in the selection of “equivalent” profiles, in the inversion procedure and in the numerical simulations of site response. The conclusions drawn by the Authors could not therefore considered to be reliable. The consequences of solution non-uniqueness should be assessed with specific analyses on a case-by-case basis, as it is difficult to draw general conclusions. It is very important that a consistent and rigorous framework is adopted both for the selection of equivalent solutions and for seismic ground response analyses.

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