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Reply on “Implications of surface wave data measurement uncertainty on seismic ground response analysis”

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ABSTRACT

We are thankful to Comina and Foti [1] (‘The Discussers’), who showed their interest in our research and raised some issues on our paper on the “Implications of surface wave data measurement uncertainty on seismic ground response analysis”. Their main concerns [1] are on the selection criteria that we adopted to select the equivalent profiles, requirement of multimodal inversion and the seismic response of those equivalent profiles. We have prepared here a detailed explanation on all the raised issues and it is shown that the variations in spectral parameters are not merely due to the so-called discrepancies raised by ‘The Discussers’.

1. Discussion

Comina and Foti [1] in their discussion on our paper expressed some doubts regarding the inversion procedure to select equivalent profiles and ground response analysis of those selected profiles, which they claimed that it needed some clarifications. The Discussers agree with the experimental uncertainty bound reported in our paper but they don't agree with the comparison of the bounds with an empirical formula proposed by Boaga et al. [2]. Empirical formula given by Boaga et al. [2] has been challenged by Socco et al. [3]. Boaga et al. [4] countered strongly what the Discussers called inconsistency at the lower frequencies. Boaga et al. [4] compared their empirical formula with that by Socco and Boiero [5], which seems to hold well. However it is irrelevant as we haven't used the expression of Boaga et al. [2] in our analysis. We had just have shown a comparison with our experimental uncertainty bound by using the proposed expression. The Discussers pointed out that the papers of Socco et al. [3] and Pettiti et al. [6] have not been cited in our paper. Socco et al. [3] commented on Boaga et al. [2] and the reply given by Boaga et al. [4] appears to be quite logical. The comment by Pettiti et al. [6] is very recently published with a detailed counter reply [7] from our side. As reply by Roy et al. [7] have addressed all the concerned issues raised by Pettiti et al. [6], we didn't consider it necessary to include the said article.

One of the concerns by ‘the Discussers’ is on the selection of equivalent profiles. Selection of equivalent profiles in Jakka et al. [8] is based on limiting value of misfit. The limiting value of misfit is calculated from the upper and lower bound curves passing through the extreme points of the standard deviation plot. For site 1, this limiting value of misfit is 0.063. Inversion is carried out with this limiting misfit and it generated ~3000 profiles. Out of 3000 generated profiles, we selected only 60 profiles covering the entire misfit band. In this selection, a proper consistency was maintained by dividing the whole misfit band into four different misfit ranges. From each range, only 15 profiles were picked to avoid the higher concentration of the selected profiles at certain misfit values and to equally distribute the profiles over the entire misfit range.

Another concern by ‘the Discussers’ is that our selected 60 profiles for site 1 are deviating from the statistical representation of the data in terms of standard deviation. As noted by ‘the Discussers’, we do agree with these deviations for site 1. But no such deviations are observed for site 2 (Fig. 2). For site 1, the presence of higher modes is quite discernible, as an upward trend is observed at higher frequencies in the standard deviation plot. The inversion by neighborhood algorithm which uses the fundamental mode of propagation obviously shows a little higher deviation at the higher frequencies since it is difficult to match the target dispersion curve without considering higher modes. Even though ‘the Discussers’ performed the multimodal inversion using Monte Carlo simulation, they could not be able to come up with the dispersion curves with a relatively much better match with error bounds (Fig. 3, Comina and Foti [1]). It is highly challenging to obtain accurate profile for inversely dispersive profile. This probably requires consideration of the mode

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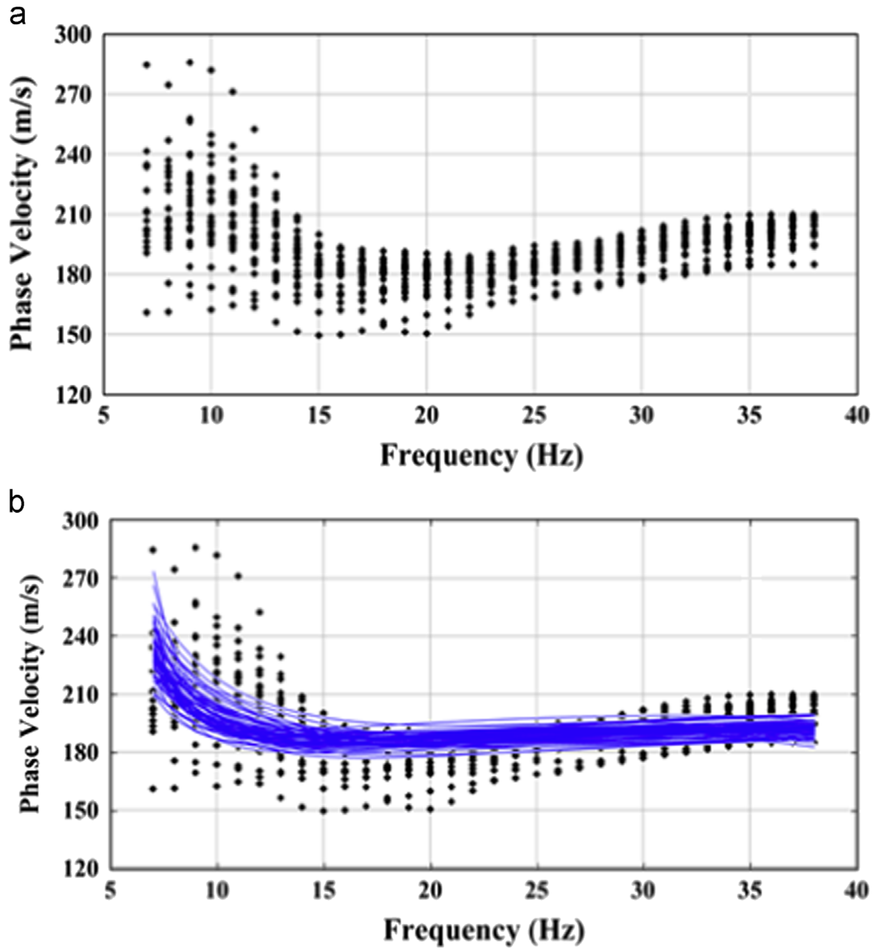

Fig. 1. (a) Variations of original data at LBS ground at IIT Roorkee site. (b) Superimposed curve of the selected 60 profiles with the original data variation curve.

superposition in the forward modeling while performing the inversion [9]. Further studies are required for refinement of inversion in this regard.

To more clearly illustrate this issue, we have provided here the original data variation of the field dispersion curves (Fig. 1a) used in the statistical analysis to calculate the standard deviation at each frequency. This figure is superimposed with the selected 60 profiles and has been presented in Fig. 1b. It is quite evident from Fig. 1b that, even though the profiles show little deviation at higher frequencies (Fig. 1 from Comina and Foti [1]), profiles are falling well within the limit of the original data variation.

The Discussers have also commented that the depth of penetration of our selected profiles is not appropriate. One can see the dispersion curves of the original data at site 1 which are having a maximum velocity of ~280 m/s at a frequency of 7 Hz (Fig. 1a), which gives a maximum wavelength of ~40 m and a penetration depth of 20 m as per their criteria. In our analysis (Fig. 7b, Jakka et al. [8]), near about 90% of the selected velocity profiles are having maximum penetration depth only up to 17 m, while half-space starts after 20 m for profiles little over 4%. More than 96% of profiles' half space starts below 20 m.

The Discussers also commented that maximum velocity variations of selected profiles are observed at half-space. This is quite obvious that the variation of half-space velocity is little higher for the selected profiles as it is directly related with the error bound at lower frequencies. Error bound increases at lower frequencies and results in the higher variation of the profiles at greater depth.

Fig. 2 below shows the superimposed curves of the selected dispersion curves and the error bounds due to data measurement uncertainty (statistical variation) of site 2. Here we can see the selected dispersion curves are exactly falling within the limit of statistical estimate. But the profiles are leading to very high variations in the spectral parameters after 1D ground response analysis as shown in our original article (Figs. 17a,b, Jakka et al. [8]). So it is very much obvious from these observations that 'the Discussers' claim ('one of our variations in the spectral parameters is mainly because of the consequences of discrepancies in equivalent profiles') does not hold good. It is very much apparent that the data measurement uncertainty associated with surface-wave tests may result in different ground motions.

Another issue raised is regarding the ground response analysis performed. However, the concern raised by 'the Discussers' on ground response analysis is not new. Pettiti et al. [6] have earlier raised similar issues on our another paper (Roy et al.[10]). These concerns have been addressed in detail by the authors (Roy et al., [7]). Roy et al. [7] explained how the approach of extension of half-space in Pettiti et al. [6] is ignoring the shallow soil responses of the profiles and resulting in the similar kind of response under an earthquake excitation.

It is a well accepted practice in site specific hazard studies to consider top 30 m soil column to investigate the local site effects in the absence of soil layering information up to the bed-rock level. As our profiles variation is up to shallow depth and our aim is to investigate the effect of these profiles on site response, we carried out the ground response analysis assigning the ground motion at the original half-space of the selected profiles. Arbitrarily extending the obtained last layer velocity up to greater depths and assuming a high impendence bed-rock has adverse effects (i.e.,