Application of Interferometric MASW to a 3D-3C Seismic Survey

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SUMMARY

Multichannel analysis of seismic surface waves (MASW) is well developed for shallow geotechnical applications. The technique has received much less attention in 3D reflection. The primary goal of this investigation is to develop an improved methodology for extracting S-wave receiver statics in 3D converted-wave (PS) reflection surveys.

The main challenge of using MASW in this context is the increased receiver spacing. To overcome this we need to include multiple sources in each dispersion analysis. Unfortunately, adding more sources increases the chance that the dispersion image will be degraded due to lateral near-surface variations. We present a methodology which incorporates interferometry into the MASW method (IMASW). This effectively repositions sources at receiver locations, reducing the region over which lateral variations can contribute to the data.

Application of this approach to a 3D-3C trial dataset provides an alternate approach for determining the S-wave receiver statics solution for converted-wave reflection surveys.

Key words: 3D, MASW, Statics, Interferometry

INTRODUCTION

The dispersion characteristics of surface-waves are known to be highly dependent on the near-surface S-wave properties (Liner, 2012). Multichannel Analysis of Surface Waves (MASW) (Park et al., 1999) is commonly used to extract these S-wave velocities for geotechnical applications. This methodology assumes that the dispersion response is primarily due to the geology in the vicinity of the receiver spread. However, Luo et al. (2007) showed that lateral variations anywhere within the source to receiver spread can influence the dispersion response.

In this investigation we have used 2D modelling to examine the impact of lateral variations. We also test a method based on interferometry which may minimise the problem, in addition to boosting the signal-to-noise ratio of the dispersion image.

The preferred methodology suggested by this modelling has been applied to a 3D seismic survey. The approach is similar to that taken by Boiero et al. (2011), but with the addition of interferometry. The aim of the dispersion investigation is to improve S-wave weathering statics (e.g. Roy et al., 2010), to be used in the 3D converted-wave (PS) processing.

2D MODELLING - LATERAL VARIATIONS AND INTERFEROMETRY

To gain an understanding on how lateral variations influence dispersion analysis, a simple 2D geological model has been examined (Figure 1). This consists of three layers, including a soil layer with zones of differing velocities, a secondary weathered layer and a more competent subweathering. The parameters were selected to be broadly representative of typical weathering environments.

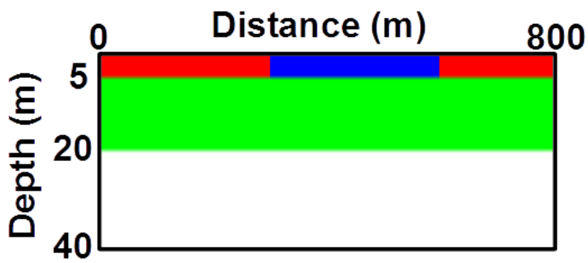

Figure 1: Geological model consisting of three layers. Velocities (V_P, V_S in m/s) are: slow soil (red): (500, 250), fast soil (blue): (700, 500), weathering (green) (1500, 700) Subweathering (white) (2400, 1200).

Figure 2 shows a typical shot record generated by finite-difference modelling of a seismic survey over the geological model in Figure 1. The general modelling scheme is outlined in Strong and Hearn (2008). This record includes receivers on both the slow (left half) and fast soil zones (right half). The general character of the ground roll on this record appears to be dependent on the geology at the receiver.

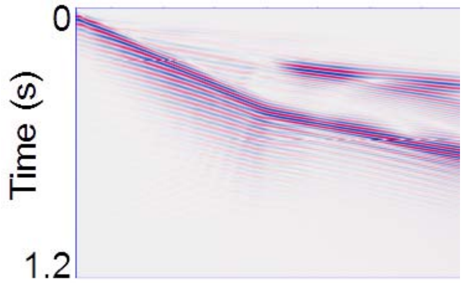

Figure 2: Sample seismic record generated by applying elastic finite-difference modelling to the geology in Figure 1. The source is in the slow soil towards the left of the model, and the receivers extend across into the fast zone, with the transition around the centre of the spread.

In noisy environments dispersion responses can be improved by stacking dispersion curves from multiple shot records. The modelled data have been used to examine how lateral variations affect this stacked response. Figure 3 compares four different scenarios (as illustrated in the first column). Each of these included 21 shots for the dispersion analysis. Consider first the results from the standard stacking approach, as shown in the centre column. When all of the shots and the receivers are in the same region (Figures 3a and 3d) the stacked dispersion images match reasonably well with their corresponding theoretical curves. Placing the sources within the other medium (Figures 3b and 3c) creates a more complicated dispersion response. This still tends to be dominated by the character corresponding to the receivers, but it becomes broken-up and smeared.

It would be beneficial if the data could be preprocessed in order to reduce the impact of the geology near the source. One possible option is interferometry. In its simplest form interferometry uses correlation algorithms to compare similarities in traces. This allows virtual traces to be generated at new locations. It is generally used to enhance different waveforms or structures.

In this investigation we use an approach similar to that employed by Hayashi and Suzuki (2004). Our implementation of the method is as follows:

- Select a group of geophones for analysis.
- Select a number of source points that include these geophones.
- For each source, window out the desired geophone spread and sort the traces by absolute offset (based on Boiero et al., 2011). Correlate every trace against those at greater offset. This creates virtual sources within the receiver spread. The offset of each virtual trace is the difference between the absolute offsets of the two original traces.
- Combine multiple source locations and perform dispersion analysis.

Theoretically, by incorporating interferometry this method should allow us to gain the benefits of surface-waves stacking, while limiting source-related lateral variation of the geology.

The right hand column of Figure 3 shows the dispersion analysis using interferometric enhancement. When the sources and receivers are in the same medium (Figures 3a and 3d) the dispersion responses are almost identical to those achieved with the stacking approach. When the sources and receivers are in different media (Figures 3b and 3c) the interferometric method generally has an improved result, with a sharper and more coherent dispersion response.

The modelled variations presented are considered more extreme than would be expected in our 3D survey. However, these experiments suggest that interferometric MASW (IMASW) could be a useful tool for improving the robustness of dispersion analyses for real datasets.

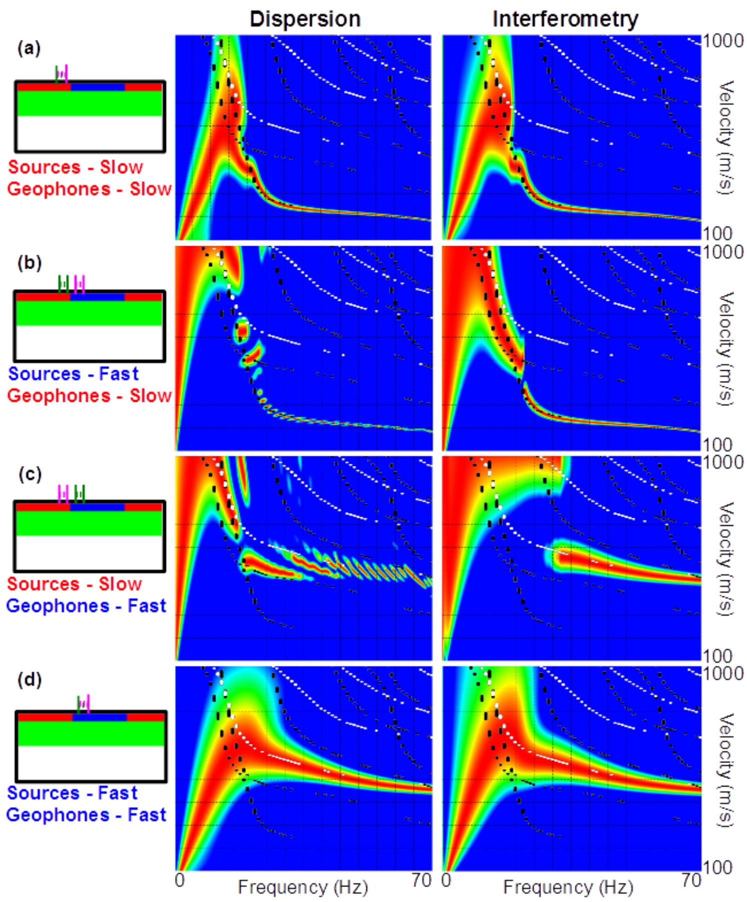

Figure 3: Comparison of surface-wave stacking MASW (centre column) and interferometric MASW (right column). (a) sources and receivers in the slow medium, (b) sources-fast receivers-slow, (c) sources-slow receivers-fast, (b) sources and receivers in the fast medium. The dispersion images are overlain by the theoretical curves for the slow (black) and fast (white) cases.

APPLICATION OF MASW TO A 3D-PS SURVEY

The main goal of this investigation is to use the MASW method to derive a near-surface S-wave velocity profile for a 3D-PS survey. The intention is to then use this to improve the S-wave receiver statics solution.

The survey area consisted of a single coal seam ranging in depth between 75m and 140m and including some known faulting (Strong and Hearn, 2011). The survey area was approximately 400m wide by 1200m long orientated in a NNE direction. A fixed spread was used consisting of 10 receiver lines spaced 30m apart and having a geophone spacing of 15m. The source lines were angled at 60 degrees, with spacings of 30m by 30m and extending beyond the receiver patch.

It is likely that the receiver spacing of this survey is too sparse to obtain consistent dispersion results using standard 2D methods. To improve the offset distribution we need to use a number of sources. However, too many sources or receivers may also distort the response. To determine the optimal parameters a range of receiver and source configurations were examined. Figure 4 compares the standard and interferometric dispersion responses for some selected cases.

Figure 4a represents the 2D case. While there is some suggestion of a dispersion curve around the 10-20Hz we would not be confident picking it using either method.

Increasing the source inclusion zone laterally by 30m either side of the receiver line (Figure 4b) improves both dispersion methods. The interferometry result is particularly good with a clear fundamental mode from 10Hz up to 40Hz.

Adding more receiver lines (Figure 4c) has had little impact on the standard dispersion analysis. The interferometry result has reduced resolution, particularly at higher frequencies.

Figure 4d shows the dispersion responses for a cross-line configuration. In this case the dispersion tends to be more complicated and noisy.

To perform the dispersion analysis on the full dataset we decided to use the binning parameters from Figure 4b, with the interferometric enhancement (IMASW). The seismic data were gridded (30m x 30m) with 30 analysis locations in the inline direction by 10 analysis locations in the cross-line direction making a total of 300 ground locations for dispersion analysis.

Figure 5 shows some representative dispersion responses from the 3D PS survey.

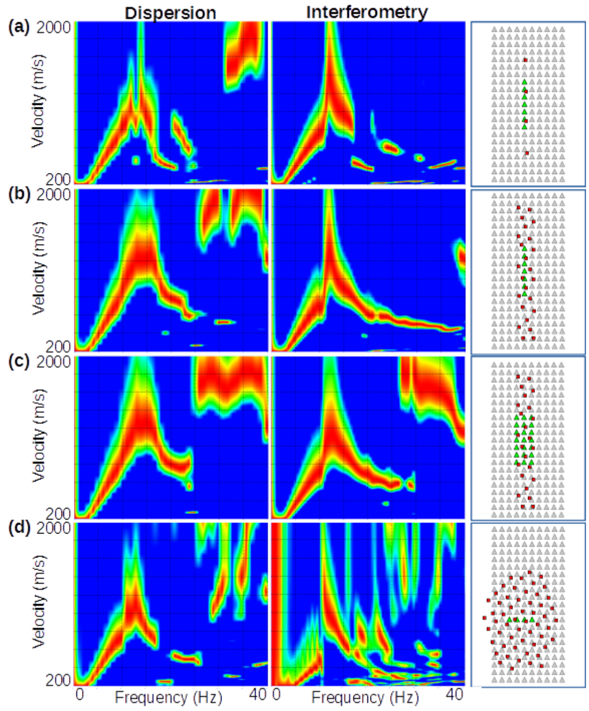

Figure 4: Comparison of the standard versus interferometric dispersion images for various binning configurations. The images on the right show the contributing receivers (green triangles) and sources (red squares).

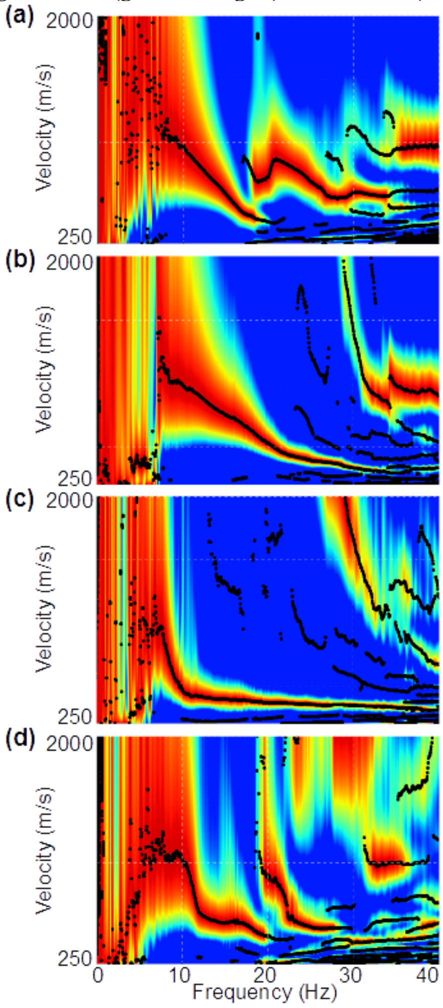

Figure 5: Interferometric dispersion images at locations of interest. The black points indicate automatically picked dispersion curves.

S-wave Velocities and Statics

The dispersion curves were inverted using the standard CPS-SURF96 package (Herrmann and Ammon, 2004) to produce a 1D S-wave profile at each location. Figure 6 shows representative velocity profiles along several of the parallel receiver lines. It is clear that there is a consistent overall trend. This suggests that the location includes a slow soil layer to approximately 5m and a slightly more competent weathering layer extending down to 20-30m. The weathering is thinner in the north (right).

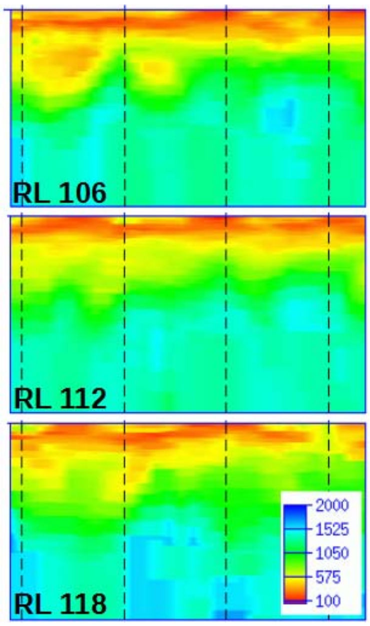

Figure 6: Inverted velocity profiles along three receiver lines. The images extend to a depth of 50m. The legend shows S-wave velocity (m/s).}

Similarly to Roy et al. (2010), we can use the S-wave velocity profile to determine the statics solution. Since the IMASW velocities tend to give smoothly varying velocities it is difficult to correctly identify the base of weathering. Therefore, we have calculated the statics to a depth below the deepest suggestion of the weathering (40m).

A number of S-wave statics methods have previously been investigated for this survey (Strong and Hearn, 2016). These include PPS refraction statics, and a statistical method call robust statics which tends to only correct for medium and short wavelength variations. Figure 7 compares these after DC bias removal and smoothing. Each of the statics methods generally suggests larger values in the southern half of the survey area. Since the robust and IMASW statics solutions tend to image the weathering at different scales, it is useful to combine the two approaches (Figure 7d). (This is similar, for example, to combining uphole-surveys and residual statics in conventional processing.) The PPS refraction and combined robust/IMASW statics are broadly imaging the same weathering structures across the survey area.

CONCLUSION

Lateral variations along a seismic spread, including in the vicinity of the source, can influence surface-wave dispersion analysis. Interferometric methods can be used to create virtual sources within the receiver spread, reducing the influence of lateral variations outside of this zone.

With this approach, reasonable dispersion curves can be extracted from sparse exploration coal-scale 3D geometries. Inversion can yield near-surface S-wave velocity profiles, which can in turn be used to improve the S-wave receiver statics solution for converted-wave reflection surveys.

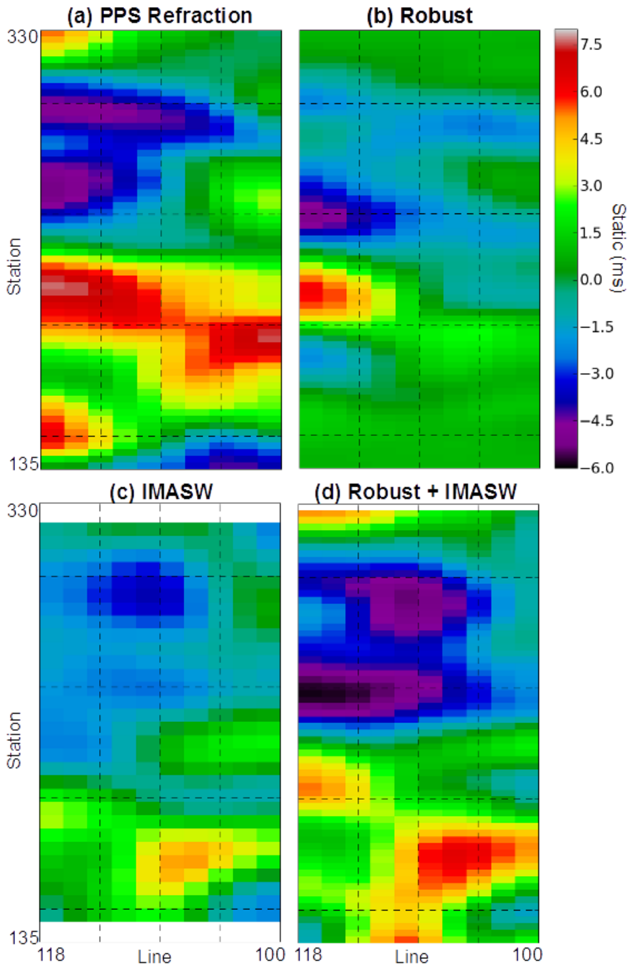

Figure 7: Map view comparison of the refraction statics for the various methods. To emphasise broad-scale similarities a 2D Gaussian filter has been applied to the data.

REFERENCES

Boiero, D., P. Bergamo, R. Bruno Rege, and L. V. Socco, 2011, Estimating surface-wave dispersion curves from 3D seismic acquisition schemes: Part 1 - 1D models: Geophysics, 76, G85–G93.

Hayashi, K., and H. Suzuki, 2004, CMP cross-correlation analysis of multi-channel surface-wave data: Exploration Geophysics, 35, 7–13.

Herrmann, R., and C. Ammon, 2004, Surface waves, receiver functions and crustal structure: Computer programs in seismology, version, 3.30.

Liner, C. L., 2012, Elements of seismic dispersion: A somewhat practical guide to frequency-dependent phenomena: Society of Exploration Geophysicists.

Luo, Y., J. Xia, J. Liu, Y. Xu, and Q. Liu, 2007, Research on Dispersion Curves of MASW: Presented at the 20th EEGS Symposium on the Application of Geophysics to Engineering and Environmental Problems.

Park, C. B., R. D. Miller, and J. Xia, 1999, Multichannel analysis of surface waves: Geophysics, 64, 800–808.

Roy, S., R. R. Stewart, and K. Al Dulaijan, 2010, S-wave velocity and statics from ground-roll inversion: The Leading Edge, 29, 1250–1257.

Strong, S., and S. Hearn, 2008, Multi-component seismicresolution analysis using finite-difference acquisition modelling: Exploration Geophysics, 39, 189–197.

Strong, S., and S. Hearn, 2011, Towards 3d, integrated p+ps seismic imaging of coal targets: Australian Coal Association Research Program (ACARP) Report, C17029.

Strong, S., and S. Hearn, 2016, Statics correction methods for 3D PS-wave seismic reflection: Exploration Geophysics (accepted for publication).