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Revealing Very Shallow Structures in a Heterogeneous Dyke through Interferometric Subtraction of Surface Waves in a Seis

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Summary

It is challenging to image the very shallow structures in a heterogeneous dyke using traditional geophysical methods. With the aim to reveal these structures, a low-budget seismic S-wave reflection survey was carried out over a dyke with a fixed-receivers array. We applied seismic interferometry to this dataset in order to retrieve surface waves and then adaptively subtracted these surface waves from the original recordings. Combined interpretation of the stacked images obtained from the original data and that from the data after adaptive subtraction reveals more complete shallow structures inside the dyke.

Introduction

As global sea level rises, safety of dykes is an area of great importance. Dykes are often very heterogeneous structures; knowing the distribution of the heterogeneities within their bodies, especailly down to 2-5 m, is crucial in evaluating the stability of the dyke taking into consideration fluid flow, suction and localized buildup of pore-pressure.

Ground-penetrating radar (GPR) is often used to investigate the body of dykes, but the performance is sometimes limited because GPR signals attenuate in the presence of electrically conductive clay layers but also due to scattering of high-frequency electromagnetic waves in the heterogeneous body. High-resolution seismic reflection method has a good potential in characterizing the heterogeneities. However, it is difficult to image the very shallow reflectors/diffractors down to 2-5 m using this seismic method, because surface waves often camouflage the shallow reflection events, especially at near offsets. This problem becomes even more severe in soft soil conditions.

When a fixed-receivers array is used in seismic reflection survey, for speeding up and keeping the costs low, the problem due to surface waves overlapping very shallow reflection events becomes serious. Because surface waves have often very close velocity to that of shear waves in the near-surface soils, and the frequency bands for surface waves and reflection events tend to be not much separated, it becomes a daunting task to filter out the surface waves through bandpass or frequency-wavenumber filtering, without affecting the shallow reflections events in the data. In this research, we have addressed the challenge of suppressing the surface waves in a fixed-receivers reflection dataset acquired over a heterogeneous dyke, to reveal the very shallow (down to 2-5 m) reflections/diffractions.

Field experiment and data processing

The field experiment was earlier carried out over a river-dyke in the north-central Netherlands. Both hammer and a high-frequency vibrator were used to generate the seismic waves. In this abstract, we illustrate our results using the sledgehammer S-wave data. The 24 geophones were fixed along the survery line, with a 0.5 m interval. We made 12 shots positioned from 12 m to 1 m ahead of the first geophone with a spacing of 1 m.

Figure 1 (a) shows a typical shot gather after automatic gain control, geometrical-spreading correction, and spectral shaping. The reflection data suffers from the presence of strong surface waves. In our case, conventional suppression approaches (e.g., f-k filtering) were not successful. Because the surface waves overlap useful reflection/diffraction events at both near and far offsets, surgical muting led to loss of data. In our processing, we used the stacking velocity (0 ms-110 m/s; 20 ms-150 m/s) as a means of discrimination to enhance the meaningful body waves while suppressing the surface waves. We then applied a bandpass filter (8-12.5-95-110 Hz) and top mute (till 20 ms) to the resulting stacked images, for a better visualization.

In order to reveal the very shallow structures in this dyke, we made use of seismic interferometry to retrieve the dominant surface waves. We then adaptively subtracted the latter from the original reflection data. This process included the following steps. (1) Multiplying the raw data by $e^{1.3*t}$ (where t is time) to boost latter arrivals. (2) Sorting the data into common-receiver gathers. (3) Correlating corresponding traces in the two common-receiver gathers. (4) Improving the S/N ratio of the retrieved surface waves and suppressing retrieved artifacts by summing equal offsets among the retrieved common-source gathers. This operation assumes lateral homogeneity, which is not true in this case. This results in a decrease of accuracy in the retrieved surface waves. (5) Selecting range of offsets from the original shot gathers that correspond to offsets in the retrieved (surface-wave) gather. (6) Adaptively subtracting the retrieved surface waves from the selected offset ranges from the original data, using a least-squares matching filter (Konstantaki et al., 2015; Verschuur et al., 1992), to obtain shot gathers where previously masked reflection/diffraction events begin to emerge. (7) Stacking the gathers obtained after adaptive subtraction using the same stacking velocities as for the original data. The same post-stack bandpass filter and mute were also applied to make the stacked events clearer.

Results

Figure 1(a) shows a shot gather (shot located at 9 m distance from the start of the shot line) due to a crossline S-wave (SH) source after the preprocessing steps described above. Figure 1(b) shows the retrieved surface waves after applying seismic interferometry. We then subtracted Figure 1(b) from Figure 1(a), which results in Figure 1(c). Figure 1(d) is the interpretation of Figure 1(c). A shallow reflection (red hyperbola) and a deeper diffraction (cyan) have become identiflable in Figure 1(d), which means that the proposed adaptive-subtraction strategy succeeded in suppressing surface-wave energy to some degree. Figure 2(a) shows the shot gather for an inline-oriented S-wave (SV) source when the source is located at 8 m distance. Figures 2(b) to 2(d) are similar to 1(b) to 1(d), respectively. We can interprete a very shallow reflection event (blue hyperbola) in Figure 2(d), which is not identifiable in Figure 2(a).

Figure 3 and 4 are the two corresponding stacked sections obtained for crossline and inline S-wave sources, respectively, following the precedures described above. Approximate depths were infered from the stacking velocity that we used, and are marked on the right side of the panels. A shallow reflector (red line, depth: ~3.5 m) begins to emerge in Figure 3(d), which is too weak to be identified in Figure 3(b). Note that the common-midpoint fold avaliable in the section after adaptive subtraction (Figure 3(d)) is much less than that in the section in Figure 3(b). A continuous reflector (blue line, depth: ~5.5 m) can be interpreted in Figure 3(b). Part of this reflector can be seen in Figure 3(d). Although the middle part of this boundary (horizontal location: 10-14 m) is not visible in Figure 3(d), it can now be identified based on information from Figure 4(d) (blue line). Due to a successful suppression of surface waves, we were able to image also at least four clear scatters (cyan hyperbolas, depth: ~16 m) in Figure 3(d).

Conclusions

We applied seismic interferometry to retrieve surface waves from a seismic reflection dataset acquired over a heterogeneous dyke. The retrieved surface waves were then subtracted from the original seismic data. As a result, originally masked, very shallow reflections/diffractions became identifiable. The resulting stacked section shows previously undetected shallow structures. Together with the conventionally processed stacked section, the stacked section obtained after interferometric suppression of surface waves provide a more complete picture of the shallow heterogeneities present in the dyke.

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References

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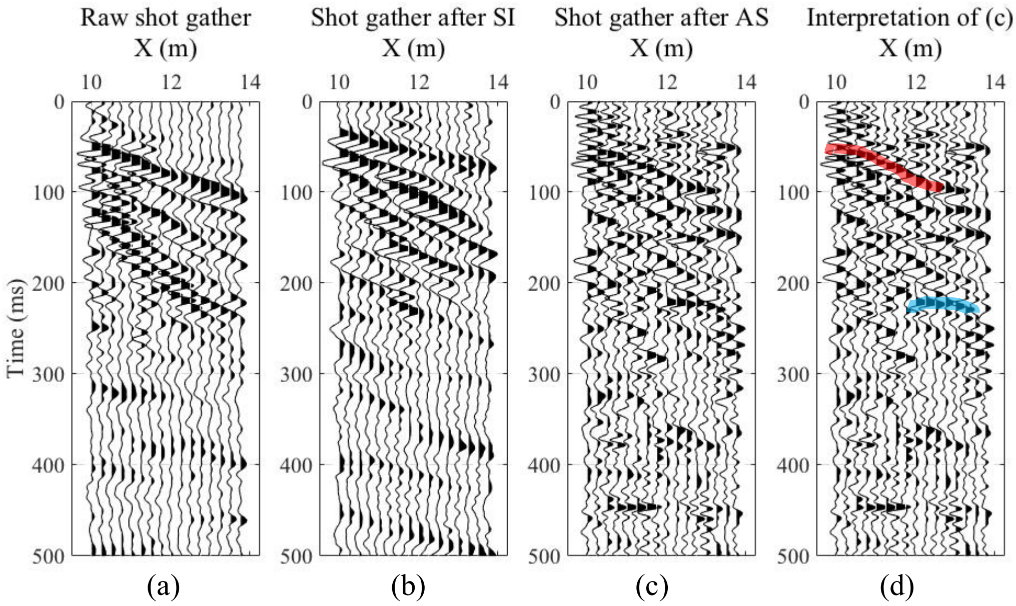

Figure 1 *A shot gather due to a crossline S-wave (SH) source at horizontal location 9 m, recored by the crossline component of 3C geophones. (a) Reflection shot gather after preprocessing; (b) retrieved surface waves; (c) result after adaptive subtraction of (b) from (a); (d) interpretation of (c). The red and cyan lines highlight some revealed reflection/diffraction events.*

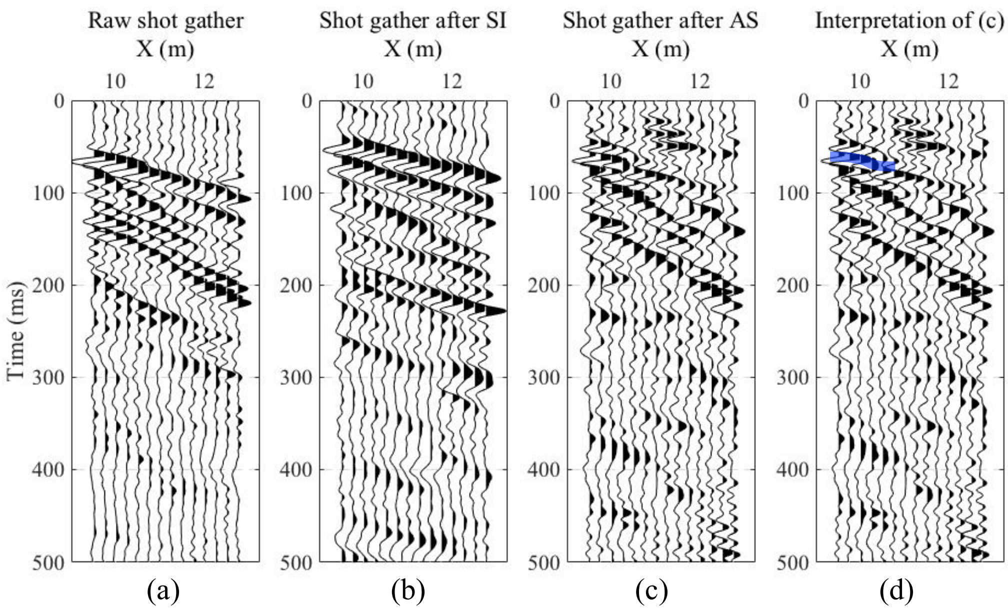

Figure 2 *As in Figure 1, but for an inline S-wave (SV) source at 8 m. The blue line highlights a revealed reflection event.*

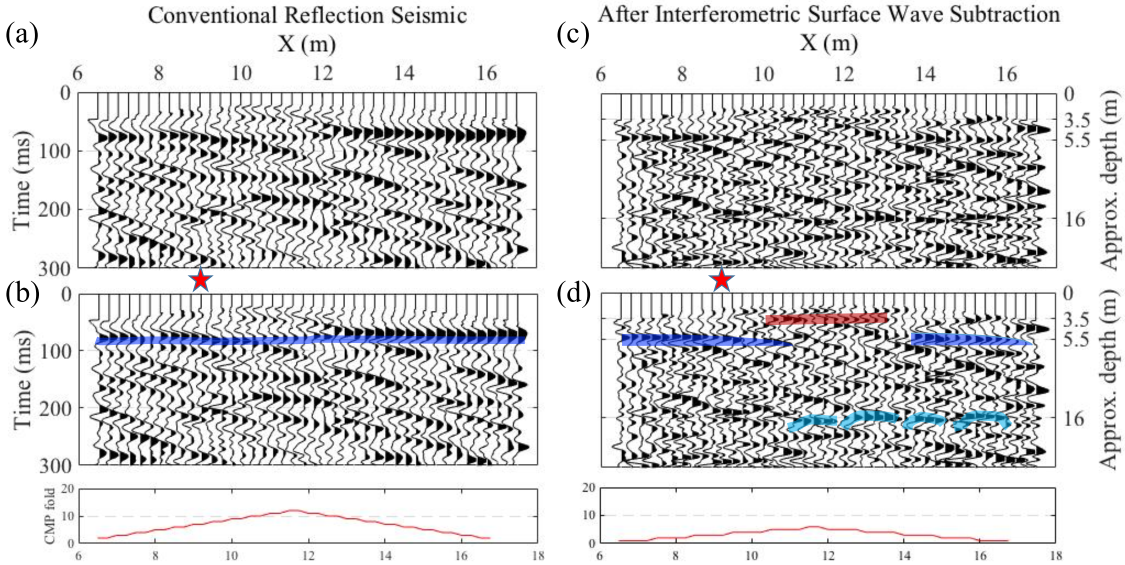

Figure 3 *Stacked sections using crossline S-wave (SH) source and crossline geophone component. Red star indicates the location of the source in Figure 1. (a) Result using the conventional reflection processing without surface-wave suppression; (b) a reflection event interpreted in (a); (c) result after surface-wave suppression using interferometry and adaptive subtraction; (d) several reflections (red and blue) /diffractions (cyan) events interpreted in (c). The common-midpoint fold distribution is shown in the lower part. Note that the surface waves (dipping events in (a)) are much reduced in (c), which makes imaging of the very shallow reflections/diffractions possible.*

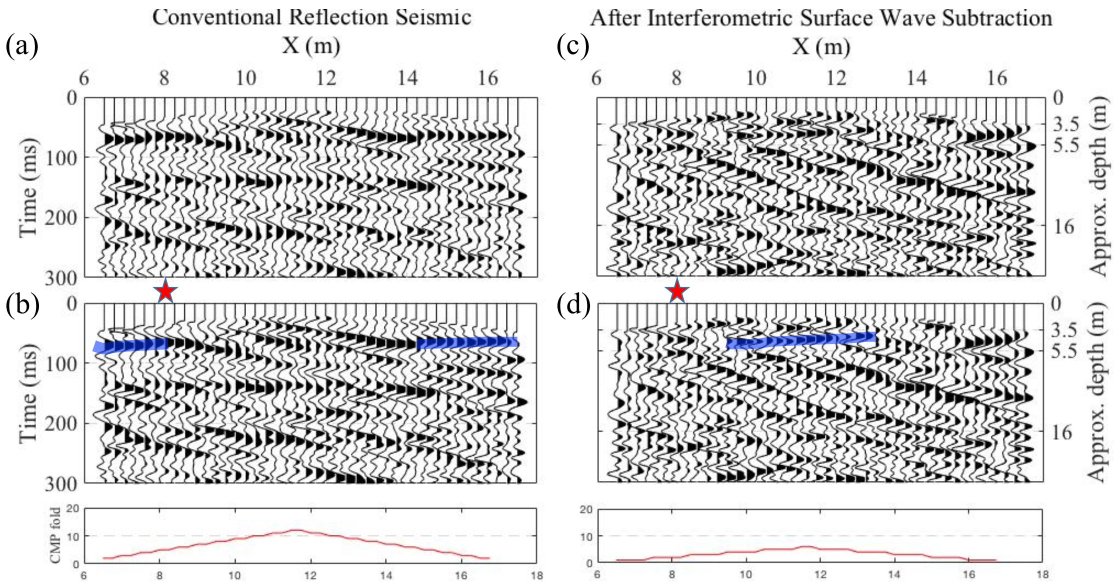

Figure 4 *As in Figure 3, but for inline S-wave (SV) source and inline geophone component.*