

Shear-velocity estimation from passive, uncorrelated records of DAS Scholte waves off the Texas coast

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SUMMARY

Passive, uncorrelated Scholte-wave data recorded by an existing telecommunication fiber-optic cable are inverted to estimate shallow and deep shear-wave velocities of marine sediments off the coast of Texas. To our knowledge, this is the first demonstration of passive Scholte wave shear-velocity estimation using distributed acoustic sensing (DAS) in shallow waters of the Gulf. The analysis uses stacked frequency-wavenumber spectra to retrieve Scholte-wave dispersion from ambient noise and a pseudo-depth transformation to construct a geologically feasible initial velocity model based on the wavelength of the first overtone observed between 0.3 and 3.3 Hz. A stable recovery of low-frequency dispersion measurements from uncorrelated ambient wavefields was possible due to the exceptional recording capabilities of the DAS array, including dense spatial sampling of 12.76 m and a total array length of about 65 km.

INTRODUCTION

Models of shear velocity and stiffness for coastal and marine sediments are important in geotechnical engineering, energy exploration, and marine geology. Such models can be constructed using geophysical methods based on dispersion analysis and surface-wave inversion.

Unlike surface waves on land, in marine seismic acquisition, interface waves such as Scholte waves are generally not part of the survey design. The recording of Scholte waves for the surface-wave inversion method requires direct coupling of the instrument to the seabed, dense sampling, and a large array aperture. Streamer-based surveys provide dense sampling of the seismic wavefield, but hydrophones may not be an appropriate choice for measuring the elastic wavefield. Ocean-bottom node (OBN) arrays can measure multiple components of the elastic wavefield, but such arrays are typically deployed on coarse grids with limited aperture lengths.

In field experiments with active marine sources, previous studies have shown that robust Scholte waves can be generated by placing a source on the seabed or a few meters above it (Ali and Broadhead, 1995; Klein et al., 2005; Tartoussi et al., 2025). The generated Scholte wave energy span frequencies from 1-2 Hz to 25 Hz, which is sufficient to profile the shear-wave velocity to depths of 5-100 m below the seabed (Kugler et al., 2005; Miao et al., 2016). Due to the coarse sampling of the deployed OBNs, dispersion spectra are typically computed in the receiver-gather domain, which can affect Scholte-wave dispersion measurements because the node coupling can vary.

In passive seismic methods, Scholte waves are retrieved from ambient seismic noise recorded over extended listening times, ranging from tens of minutes to many hours. Such acquisition requires a logistically suitable, seabed-coupled, multi-

channel recording system, e.g., an ocean-bottom cable (OBC) or a telecommunication fiber-optic cable deployed on the sea floor. The frequency range of passive Scholte waves varies by study area: 0.2-2.5 Hz in the North Sea (Muyzert, 2007; Re et al., 2024), 0.25-4.0 Hz in Monterey Bay, California (Lindsey et al., 2019; Cheng et al., 2021), 0.6-1.0 Hz offshore Sanriku, Japan (Spica et al., 2020), 0.3-2.0 Hz offshore Belgium (Williams et al., 2021), and 0.25-1.3 Hz offshore France in the Mediterranean Sea (Guerin et al., 2022). Typically, cross-correlation functions (CCFs) of ambient noise are calculated to measure Scholte-wave dispersion. The CCF might be necessary for coarsely sampled multi-channel systems, such as OBN or OBC arrays. However, in the case of telecom DAS arrays, the ambient wavefield is already densely sampled, and thus the Scholte-wave dispersion can be extracted without CCFs.

In this study, we investigate passive Scholte wave data recorded by an existing telecommunications fiber-optic cable deployed off the Texas coast (Figure 1). We retrieve the Scholte-wave dispersion from the uncorrelated ambient wavefield over the frequency range from 0.3 to 3.3 Hz by leveraging the dense, continuous spatial sampling along the seafloor provided by DAS. We invert the measured dispersion of the first overtone, which is stronger than the fundamental mode. The estimated shear wave velocity profile is characterized by low shear wave velocities on the order of 90 m/s or less in the shallow section and by shear velocities of about 800 m/s in the deeper portion. The dense sampling of the DAS array enables the measurements of an unaliased seismic wavefield at high frequencies, and its large aperture provides sufficient resolution to differentiate between modes at low frequencies.

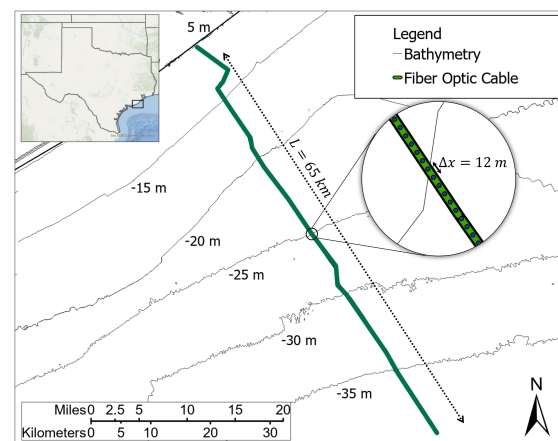


Figure 1: Overview of the study area off the coast of Freeport, Texas. The 65 km long segment of the telecommunication fiber-optic cable is shown in green. The water depth along the cable increases gradually from the shoreline to approximately 40 m. The DAS interrogator unit is located onshore and samples the fiber-optic cable at 12.76 m intervals.

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In the following section, we discuss the properties of the Scholte waves measured by the DAS instrument. Then, a detailed description of the acquisition geometry, data characteristics, and processing workflow is provided in the field data application section.

SCHOLTE WAVE PROPERTIES

A Scholte wave is an interface wave that travels along the fluid-solid interface with a phase velocity that is smaller than the compressional-wave velocity in the fluid and the lowest shear-wave velocity in the solid (Biot, 1952; Strick and Ginzburg, 1956). The depth to which a Scholte wave has a significant displacement is proportional to its horizontal wavelength (Stein and Wysession, 2009).

In practice, one half of the horizontal wavelength can be used to map the phase velocity v_x to the depth domain and to build an initial velocity model (Foti et al., 2018). In this study, we define the wavelength without including a factor of 2π as $\lambda_x = v_x/f$, where v_x is the phase velocity of the Scholte wave and f is the frequency of the source. Given the frequencies f_{obs} and velocities v_{obs} observed in a dispersion spectrum, we calculate the pseudo-depth $\hat{z}$ as

$$\hat{z} = \frac{1}{2.5} \frac{v_{obs}}{f_{obs}}. \quad (1)$$

This pseudo-depth transformation is mode dependent and provides only an approximate mapping between observed dispersion and depth sensitivity. Using this transformation, a geologically reasonable initial shear-wave velocity model is constructed and used as input to the inversion workflow.

Theoretical dispersion curves for a full set of modes can be computed using reflectivity-based or global-matrix formulations of the elastodynamic boundary-value problem; however, such calculations do not guarantee which modes will actually be excited in a field experiment. The dispersion spectra of passive Scholte waves, measured by a distributed acoustic sensing system, typically include one or two modes (Cheng et al., 2021; Williams et al., 2021; Spica et al., 2020; Re et al., 2024). When only one mode is present, it is usually interpreted as the fundamental mode rather than the first overtone. In active seismic data from Kugler et al. (2005), the dispersion spectra of Scholte waves comprise only one mode, which is interpreted as the first overtone, since its phase velocity is too high to correspond to a fundamental mode given the soft marine sediments in that study area.

FIELD DATA APPLICATION

The central Texas shelf is covered by a thick sequence of unconsolidated to weakly consolidated marine sediments (Pirmez et al., 2012). As a reference for plausible shear-wave velocity values in shallow marine sediments, we consider the model constructed by Ritzwoller and Levshin (2002) from seismic data collected at approximately 5 m water depth off the coast of Louisiana. In that model, the depth gradient in the top 20 m is described as very high, consistent with models of rapidly compacting marine sediments (Hamilton, 1979).

Data Acquisition

A fiber-optic cable installed about 1 m below the seabed for telecommunications with offshore platforms was used to measure axial strain along the fiber by connecting it to a distributed acoustic sensing (DAS) interrogator unit (Figure 1). The interrogator is installed onshore at the landing station, and the water depth along the cable gradually increases from 0 at the beach to about 40 m at 65 km from the coast. This segment of the fiber-optic cable is sampled by the DAS unit using a gauge length of 24 m and a channel spacing of 12 m. This configuration yields 5091 channels over a distance of 65 km, suitable for continuous multichannel recording of the ambient noise.

Example of passive data in Figure 2 illustrates the seismic and ocean wave phenomena recorded by the DAS cable. The strong events with low apparent velocities are the ocean-gravity waves, which represent an ocean mass movement. Their dispersion depends on water depth and gravity, following the well-known linear gravity-wave dispersion relation. As ocean-gravity waves approach the beach, their apparent velocity increases.

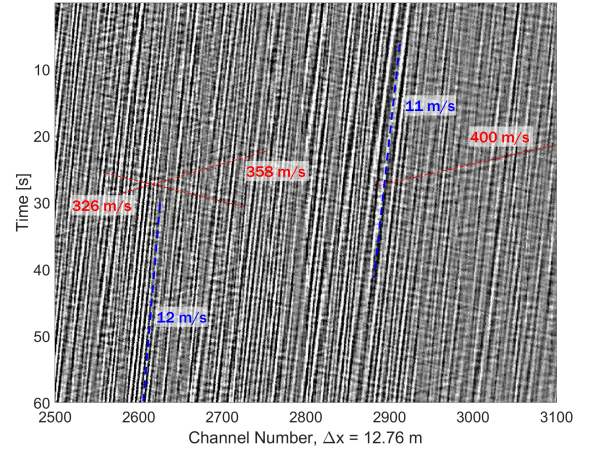


Figure 2: Example of raw passive DAS data for the middle portion of the cable at about 25 m water depth. The observed events include ocean-gravity waves with apparent velocities of 11 to 12 m/s and seismic surface waves with apparent velocities of about 300 to 400 m/s. Seismic surface waves are the signal of interest used to estimate shear wave velocities.

The subtle linear arrivals with apparent velocities ranging from 300 to 400 m/s correspond to seismic interface waves propagating along the fluid-solid boundary at the seafloor. Based on their apparent velocities, dispersive behavior, and propagation characteristics, these arrivals are identified as Scholte waves. Their dispersion is measured to estimate the shear-wave velocity structure of the shallow subsurface. Ocean-gravity waves and Scholte waves exhibit distinct slopes in the time-distance domain and can thus be effectively separated in the frequency-wavenumber domain.

Frequency-Wavenumber Analysis

The raw passive DAS data were transformed into the frequency-wavenumber (f - k) domain using a two-dimensional Fourier

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transform on a uniformly sampled space-time grid, after which the f - k spectra were stacked to accumulate a coherent signal and suppress transient fluctuations. An example of such f - k spectrum shown in Figure 3 is obtained by stacking 360 1-minute-long records containing 480 channels (an array length of about 6,125 m). A similar strategy for retrieving coherent Scholte waves from ambient noise data is effective by Spica et al. (2020), who also focused on estimating shear velocities from passive Scholte-wave data.

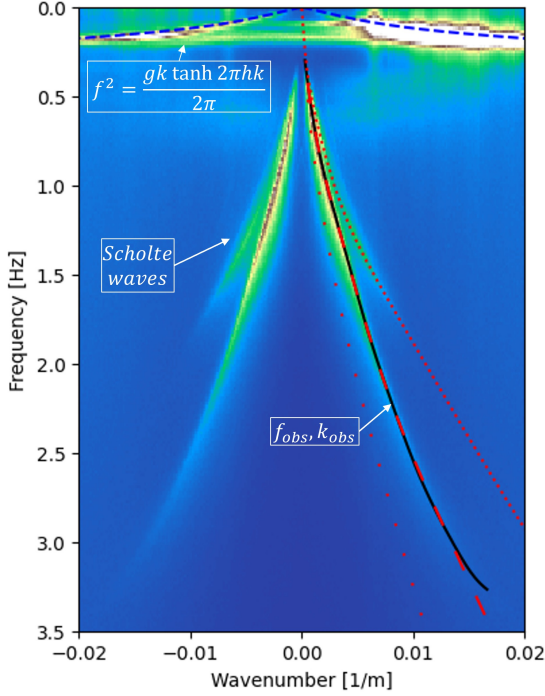


Figure 3: Frequency-wavenumber spectrum of passive DAS data. The dashed blue line shows the dispersion relation for ocean-gravity waves computed for a water depth of 25 m. The black line marks the picked dispersion of the first overtone used for inversion, while the red curves show the fundamental and overtone modes computed for the final velocity model.

The dominant frequency range of ocean gravity waves in these data is approximately 0.05 to 0.3 Hz. The energy of the ocean gravity waves primarily occupies the frequency-wavenumber pairs linked by the linear dispersion equation, although spectral leakage to the lower wavenumbers occurs. The Scholte waves are observed at frequencies of about 0.3-1.8 and 0.3-3.3 Hz for the fundamental mode and first overtone, respectively. The second overtone is not recognizable in this spectrum; however, it is observed for other portions of the DAS cable. The first overtone is observed to be stronger than the fundamental mode, a behavior that has been reported in shallow-water settings.

The stacked f - k spectra have also been computed with 960 and 240 channels, centered at the same location as the spectrum in Figure 3. The longest window of 960 channels (12,250 m) was used to achieve an adequate resolution of signal wavenumbers

at low frequencies of around 0.5 Hz. The shortest window of 240 channels (3060 m) was set to avoid spatial averaging and dispersion smearing at higher frequencies (about 3 Hz). These stacked f - k spectra were used to pick the first overtone for both positive and negative wavenumbers. Given the observed wavenumbers and frequencies, the observed phase velocities were calculated as $v_{obs} = f_{obs}/k_{obs}$, where k_{obs} is expressed in cycles per unit distance. All sets of observed frequencies and phase velocities have been merged and resampled using spline and polynomial functions, which yield the dispersion measurements shown as the black line in Figure 3.

Scholte Wave Inversion

The Scholte wave inversion was performed using the dispersion of the first overtone. The initial velocity model was built based on the pseudo-depth transformation (Equation 1). For this initial model, the theoretical dispersion curves were computed and compared with the measured dispersion. This analysis showed that the initial model overestimates shear wave velocities at high frequencies (3.0-3.3 Hz) and slightly underestimates them at low frequencies (0.3-0.5 Hz). The final velocity model was obtained using a local, gradient-based inversion workflow described by (Herrmann, 2013).

For the inverted velocity model, the analytical curves were also computed and then overlaid on the stacked f - k spectrum (Figure 3). For the fundamental mode, the theoretical curve can be verified with the observations only up to 1.8-2.0 Hz. For the first overtone, the theoretical curve closely matches the observed dispersion, except at frequencies above about 3.0 Hz. For these frequencies, the thickness of the shallowest subsurface layer is comparable to the water depth, and local bathymetric variability might contribute to the observed mismatch, as it is not properly accounted for when an average water depth is used.

Figure 4 shows the initial and final velocity models for the first 400 m below the seafloor and reference models from the literature. The pseudo-depth transformation provides a geologically feasible initial model, with a depth gradient comparable to that of commonly used empirical marine sediment models in the depth interval from 40 to 110 m. The inversion reduces the initial velocity values and, for the final profile, attains velocity values comparable in magnitude to those reported for shallow marine sediments constructed from multi-component data acquired off the Louisiana coast Ritzwoller and Levshin (2002).

For the depth interval between approximately 250 and 650 m, the depth gradient of the final model is slightly larger than that of commonly used empirical marine sediment models (Figure 5). An independent shear-wave velocity profile was derived from well logs for a well located near the DAS cable at a water depth of 10 m. Because the shallow section above approximately 1,000 m true vertical depth below the seafloor is not logged, the well-log-based shear velocities require extrapolation toward the mud line. This extrapolated profile systematically overestimates shear-wave velocities relative to those obtained from the Scholte-wave inversion, highlighting the uncertainty associated with shallow extrapolation in the absence of direct measurements.

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The shear-wave velocity structure inferred from passive Scholte-wave dispersion is consistent with previously reported amplitude-based observations of spatial variability in seabed stiffness along the same telecommunications cable. Those amplitude variations, documented using independent DAS-based analyses, reflect laterally heterogeneous mechanical properties of the shallow seafloor and provide a kinematic–dynamic context for the dispersion-based velocity estimates (Bakulin et al., 2026).

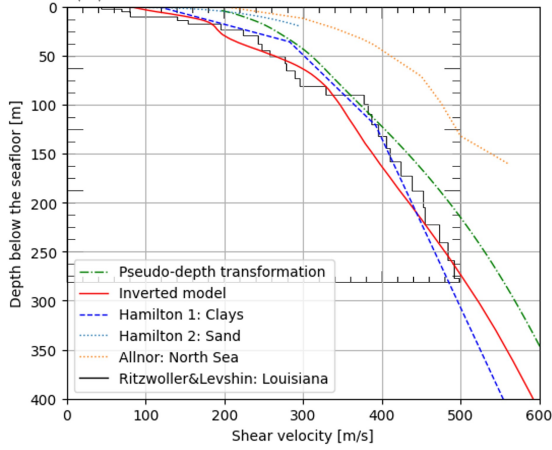


Figure 4: The upper 400 m of shear-wave velocity profiles estimated from passive Scholte-wave data recorded off the Texas coast, shown together with commonly used reference models for marine sediments (Hamilton, 1979; Allnor et al., 1997; Ritzwoller and Levshin, 2002). The initial model (constructed from a wavelength-based depth approximation) and the final inverted model are shown for comparison. The final velocity profile is systematically lower than the initial model and is closer to clay- and mud-dominated reference trends than to sand-rich models, consistent with fine-grained marine sediments in the study area.

CONCLUSIONS

The passive Scholte-wave data recorded by a telecommunications fiber-optic cable deployed approximately 1 m below the seabed were used to estimate the shear-wave velocity structure of shallow marine sediments. The combination of a dense sampling (12.79 m), a long spatial extent (65 km), and strong coupling of the buried cable to the seafloor allowed the stable frequency-wavenumber analysis of uncorrelated ambient noise and robust measurement of Scholte-wave dispersion over frequencies from 0.3 to 3.3 Hz. As a result, shear-wave velocity structure was constrained from shallow depths to approximately 1,000 m below the seabed. The resulting shear-wave velocity profiles are internally consistent and comparable in magnitude to previously reported values for shallow marine sediments. These results demonstrate that passive ambient-noise measurements acquired with distributed acoustic sensing can provide robust constraints on subsurface shear properties in shallow-water environments, particularly when long-aperture, densely sampled offshore fiber-optic infrastructure is available.

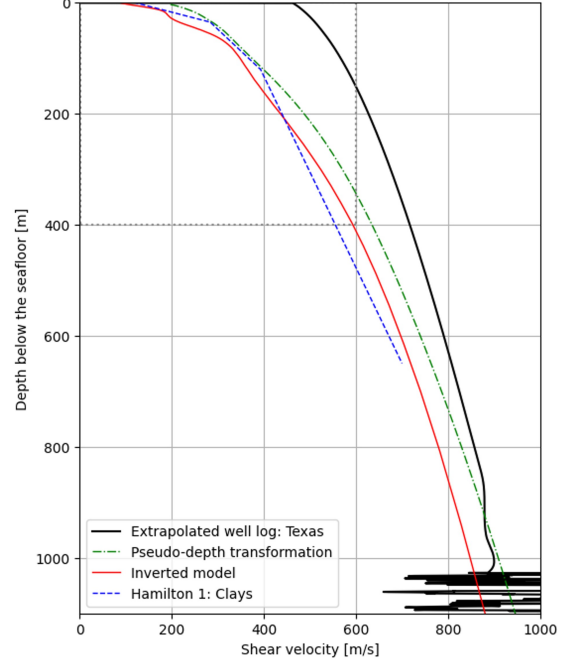


Figure 5: Shear-wave velocity profiles estimated from passive Scholte-wave dispersion along the Texas coast. The well-log-based shear-wave velocity profile was derived independently of the passive DAS analysis and requires extrapolation to the seafloor because of the absence of shallow log measurements. The comparison highlights the sensitivity of passive Scholte-wave inversion to shallow and intermediate depths that are poorly constrained by conventional well logs.

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