Analysis of passive DAS data for observation of microseisms and extracting Scholte wave dispersion in shallow water

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Abstract: *In recent years, the emerging technology of Distributed Acoustic Sensing (DAS), measuring the strain in a fibre-optic (FO) cable caused by acoustic waves, has been used for monitoring and imaging of trains, pipelines, earthquakes, whale and oil fields, etc. DAS systems have the advantage over traditional receiving systems since it can provide densely sampled array along the FO cable and wide-band signals, especially low frequency response. In this study, A patch of two-hour continuous strain data from the Tampnet DAS dataset released from "The Global DAS Month of February 2023 is analysed. The ambient noise is dominated by periodic shoaling ocean surface waves and contains the interaction of ocean oppositely propagated ocean wind-waves. The primary and secondary microseisms are separated by frequency-wavenumber decomposition due to the good low-frequency response of the DAS system. Greens' functions from the passive strain data are retrieved by passive seismic interferometry. Dispersive Scholte waves are extracted from the Green's function using time-frequency analysis. The shear-wave velocity profile in the upper sediment layer is estimated by inverting the dispersion curve of the Scholte wave in a nonlinear geoacoustic inversion algorithm.*

Keywords: *Distributed acoustic sensing, microseisms, frequency-wavenumber analysis, Scholte wave dispersion, shear wave velocity*

1. INTRODUCTION

In recent years, the emerging technology of Distributed Acoustic Sensing (DAS), measuring the strain in a fibre-optic (FO) cable down to nano strain levels caused by acoustic waves, has been used for monitoring and imaging of trains, pipelines, earthquakes, whale and oil fields, etc. DAS systems have the advantage over traditional receiving systems since it can provide densely sampled array along the FO cable and wide-band signals, especially low frequency response.

DAS data are generated by an interrogator that transmits laser pulses into a fibre and interrogates the Rayleigh backscattering caused by density fluctuations in the fibre. These density fluctuations are detected as phase changes in the backscattered light. The interrogator calculates the time-differentiated phase change of the backscattered response from consecutive sweeps and converts it to the longitudinal strain of the corresponding fibre position. The number of channels over which the phase differentiation is performed is called the gauge length (GL) [1].

DAS technology has been applied to many disciplines both on land and in underwater, including sub-surface monitoring, earthquake seismology, geophysics exploration, passive acoustic monitoring of ships and monitoring and tracking whales [2-6]. The existing FO telecom cable deployed on the seafloor along the coastal area can be used for monitoring underwater infrastructure and underwater noise generated by ships and marine life. A few km long DAS array can detect ocean surface gravity waves in the coastal environment, sense the dynamic pressure produced by the surface gravity wave down to the seafloor, and record seafloor-bounded Scholte waves [3].

In this paper, a patch of two-hour continuous strain data from the Tampnet DAS dataset released from “The Global DAS Month of February 2023” [7] are analysed. The good low-frequency response of DAS system in shallow water is demonstrated by frequency-wavenumber analysis. The primary and secondary microseisms are generated by ocean surface gravity waves and the interaction of oppositely propagated wind-waves reaching the seafloor to convert into seafloor-bound Scholte waves are observed. The Scholte wave is obtained from the Green’s function retrieved by passive seismic interferometry and the shear wave velocity profile is estimated by using the dispersion property of the Scholte wave.

2. DAS DATASET

DAS dataset used in this study is from “The Global DAS Month of February 2023” [7]. It was a Global DAS Month campaign and a total of 32 individual DAS systems acted jointly as a global seismic monitoring network and 32 sub-datasets were generated for free download. The Tampnet sub-dataset is selected in this study. The dataset was recorded by OptoDAS interrogator from Alcatel Submarine Networks (ASN) from a telecom cable with landing in Lowestoft, UK and extended NE to the Southern North Sea. The FO cable layout and the bathymetry of the area are illustrated in Fig. 1. The recorded strain data were from the first 80 km of the cable deployed at a water depth from 20 m to 50 m. The related parameters of the dataset are listed in Table 1. The dataset is not entirely continuous in time but contains patches of continuous data related to seismic events. A patch of around 2-hour continuous strain data recorded on 10th of February is selected and analysed.

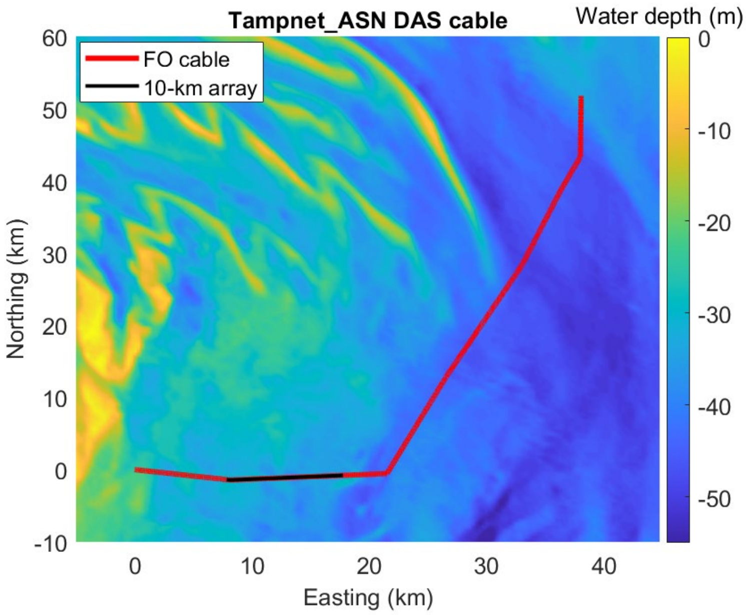

Fig.1: Tampnet FO cable layout and the bathymetry.

Parameter	Value
FO cable length [m]	80,000
Gaugh length [m]	20
Channel spacing [m]	20
Number of channels	40000
Sampling frequency [Hz]	125

Table 1: DAS dataset parameters.

3. DAS DATA PROCESSING AND RESULTS

1) Detection of Ocean surface waves

Using a long DAS array perpendicular to the coastline, the good low-frequency response of the DAS system can be used to detect the ocean surface gravity waves. Fig. 2 (a) plots 5-minute raw stain data from a 10 km DAS array (black part in Fig. 1) which is perpendicular to the shoreline. It shows periodic oscillations mainly propagating towards the shore. PM and SM are separated by a frequency-wavenumber decomposition as shown in Fig. 2 (b). Figure 3 is an enlarged version of Fig. 2 (b) at two different frequency bands. PM in Fig. 3 (a) shows the asymmetric dispersive wave trains in the frequency band between 0.02 and 0.5 Hz, propagating landward with stronger amplitude and oceanward with weaker amplitude that corresponds to a reflection off the shore. The red curve in Fig. 2 (b) and Fig. 3 (a) is the theoretical dispersion curve of the linear gravity wave in shallow water with a depth of h = 30 m given in (1).

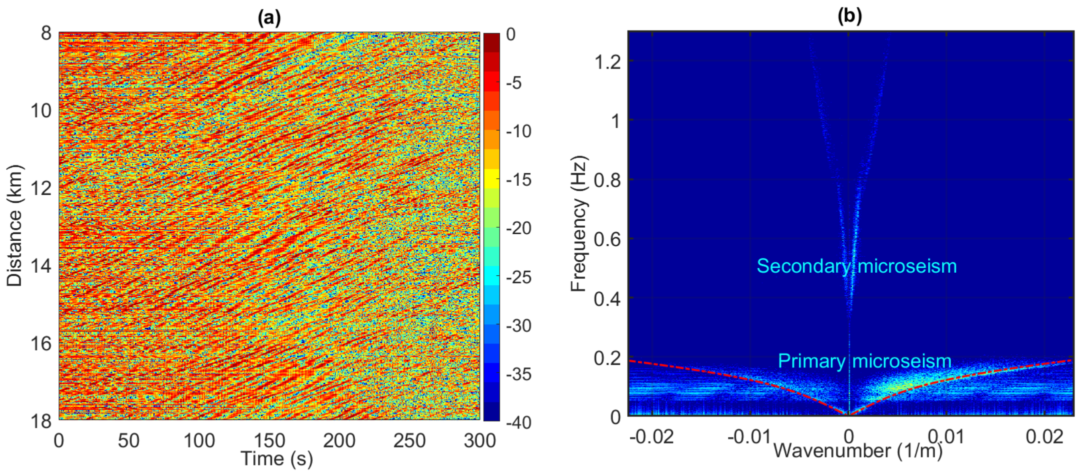

Fig.2: Microseism analysis of strain data from a 10-km array shown in Fig. 1. (a) Raw strain data. (b) Frequency-wavenumber decomposition of the strain data. Red curve is the theoretical dispersion of ocean surface gravity wave in shallow water (h=30 m).

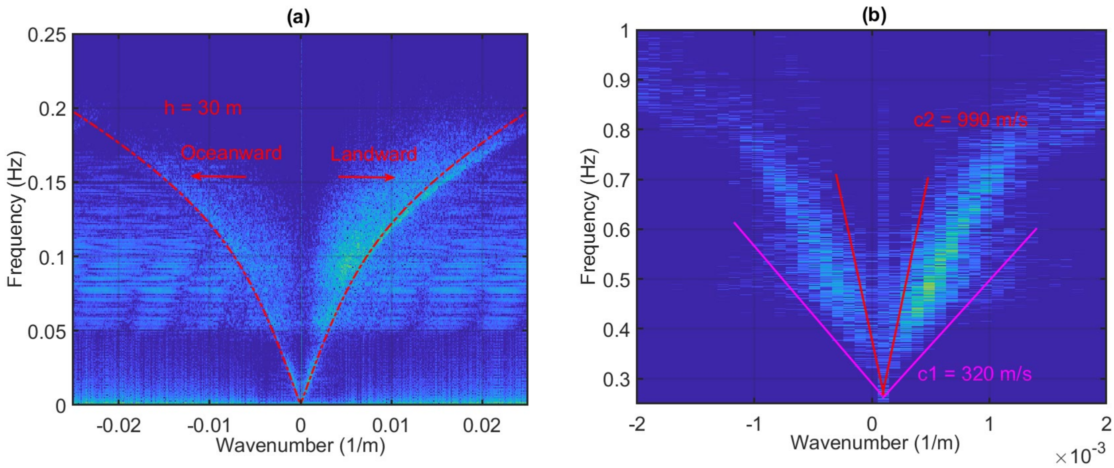

Fig. 3: Enlarged version of Fig. 2 (b). (a) PM decomposition and the dispersion curve of the gravity wave. (b) SM decomposition showing seafloor bounded Scholte wave.

$$\omega = \sqrt{g \cdot k \cdot \tanh(k \cdot h)}, \quad (1)$$

where ω is angular frequency, g is gravity acceleration, k is wavenumber, and h is water depth. The red curve fits the wave trains well. The interaction of wind waves in the opposite directions results in SM in the frequency band of 0.25 - 1.0 Hz, that reaches the seafloor and converts to Scholte wave with symmetric components traveling with the speed between the elastic speed of shallow sediments (200 - 500 m/s) and the acoustic speed of water (1500 m/s) [3].

2) Estimation of sediment shear wave velocity

The received passive strain dada are used to estimate the shear wave velocity profile in the sediment by performing the passive seismic interferometry. A bandpass filter of 0.6 -

5.0 Hz is applied to the passive strain data from a 1.2 km array, that is 60 DAS channels, to remove the high frequency components. The bandpass filtered strain data plotted in Fig. 4 (a) show the evenly distributed ocean noise. The passive seismic interferometry is performed on the bandpass filtered data to retrieve Green's functions [8]. The averaged Green's functions are shown in Fig. 4 (b). The Green's functions contain dispersive Scholte waves. The dispersion curve of the Scholte waves is extracted from the retrieved Green's functions by applying time-frequency analysis, τ-p transform and plotted in Fig. 5 (a), which is named as measured data.

The estimated dispersion curve is used as input data to a non-linear geoacoustic inversion algorithm, ASSA, to estimate the seabed shear wave velocity profile. An earth model with one horizontally homogenous sediment layer overlaying half-space is selected, where the shear wave velocities in the sediment and the half-space, and the sediment layer thickness are estimated parameters, while other geoacoustic parameters are kept constant during the inversion. The predicted dispersion curve is plotted in Fig. 5 (a), and it fits the measured dispersion curve very well. The estimated shear wave velocity profile is plotted in Fig. 5 (b) which indicate a soft sediment layer. The scatter plot of the objective function values for the estimated parameters are displayed in Fig. 5 (c) which gives a qualitative sensitivity of the estimated parameters and a rough measure of the uncertainties of the estimated values. All the three parameters are well estimated as their plots appear like "Tornado". The inversion results indicate a soft sediment layer with the shear wave velocity of 360 m/s and the thickness of 65 m, and the shear wave velocity in the layer beneath is about 410 m/s.

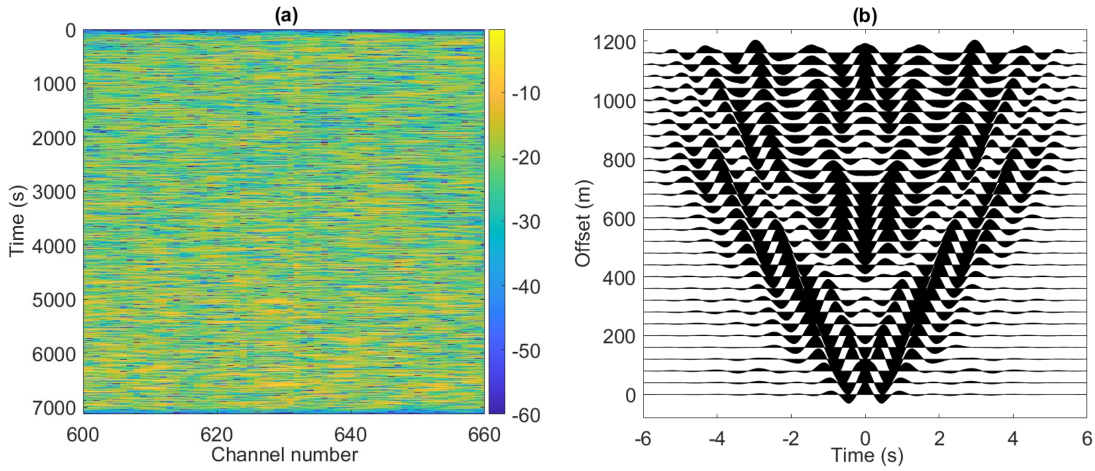

Fig. 4: (a) Bandpass filtered 60 channels of 2-hour strain data. (b) Averaged Green's functions of 60 channels retrieved by passive seismic interferometry.

4. CONCLUSION

A two-hour passive DAS strain data from the Tampnet DAS dataset are analysed to detect the ocean surface gravity waves and estimate shear wave velocity of the shallow sediments. Frequency-wavenumber decomposition separates the PM and SM thanks to the good low-frequency performance of the DAS system. This low frequency analysis can be used to detect the surface wave generated by vessels to characterize the vessel's speed and dimension. Green's functions are retrieved by performing passive seismic interferometry, which contains dispersive Scholte waves. Shear wave velocity profile of the shallow sediments is estimated using the extracted dispersion curve of the Scholte wave by ASSA inversion. The inversion results indicate a soft sediment layer and the penetration depth around 100 m.

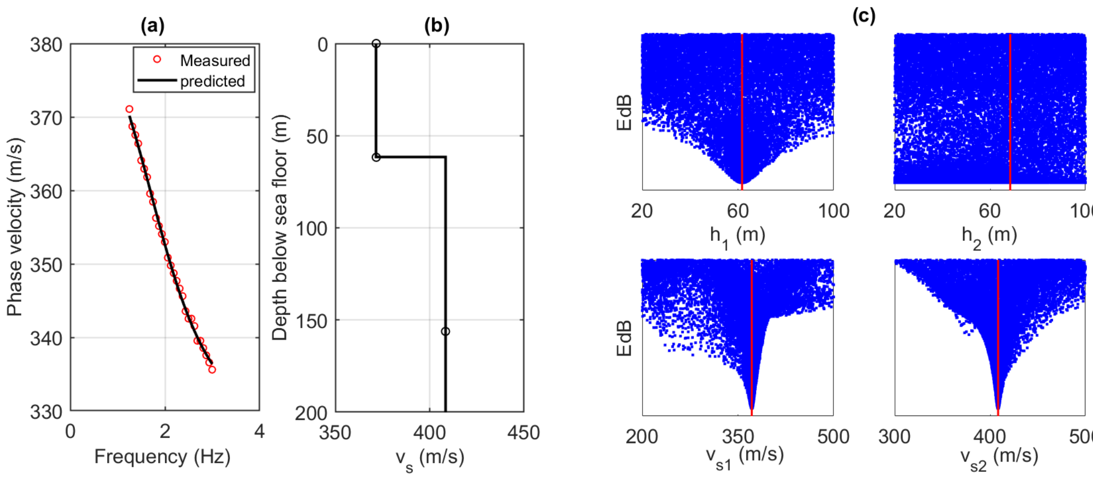

Fig. 5: ASSA inversion results. (a) Estimated and predicted dispersion curve. (b) Estimated shear wave velocity profile. (c) Scatter plot of the objective function values of the estimated parameters.

5. ACKNOWLEDGEMENTS

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