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Authors(s)	Trafford, Andrew, Donohue, Shane, Ellwood, R., Godfrey, A., Wacquier, Loris
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THE APPLICATION OF DISTRIBUTED ACOUSTIC SENSING FOR SHALLOW MARINE INVESTIGATIONS – AN INTERTIDAL CASE STUDY

Introduction

Typically, there is a paucity of geotechnical information available to designers of offshore foundations for marine renewable structures, which often results in highly conservative designs. Recent innovations offshore (e.g. McGrath et al. 2016; Long et al. 2020)) seismic surface wave (SW) measurements have highlighted their potential for providing offshore geotechnical information, thereby reducing design uncertainty. There is also an increasing recognition of the value of these measurements from the geotechnical industry, with Lunne (2013) recommending that measurements of seismic shear wave velocities (V_s) should be standard practice for important offshore site investigations. V_s is related to the small strain shear modulus G_{max} , which is a critical input parameter for several applications, including static and dynamic analysis of foundation systems, soil liquefaction analysis and input for advanced constitutive soil models. The main disadvantage of current offshore SW practice is a relatively slow data acquisition procedure, which, in turn reduces the spatial coverage of the approach.

Over recent years, fibre-optic technologies have been used for an increasing array of applications. Distributed sensing of fibre optic cables, has been shown to enable continuous, real-time measurements along the entire length of a fibre optic cable. Unlike traditional sensors, distributed sensing does not rely upon individual sensors but utilises the full length of an optical fibre as a sensing element. This enables dense spatial sampling, at the metre scale, over a distance of tens of kilometres. Fibre-optic sensors measure the response to external forces that are applied to it. This usually involves transmitting a pulsed coherent optical laser signal through the fibre and measuring the naturally backscattered light (Nikes & Ravet 2010). The phase of Rayleigh backscattered light along an optical fibre is well suited for monitoring dynamic strain changes, with a high spatial and temporal resolution. The application of this approach for ground-motion detection is called distributed acoustic sensing (DAS), and current technologies are capable of resolving nano-strain deformation (Masoudi & Newson 2017). Seismic energy will cause small strain ground deformations that are measurable by a fibre-optic cable (Jousset et al. 2018).

The purpose of this study is to assess the feasibility of using DAS to measure seismic surface waves for use in offshore geotechnical investigations.

Dollymount Strand, Dublin

Dollymount Strand is a popular beach close to Dublin city centre. It is a wide sandy beach which runs the entire length (5km) of Bull Island. The island was created following the construction of the North Bull Wall, in the 19th century, as a measure to stop silting of the main shipping channel.

Figure 1 : Location plan showing Bull Island, Dollymount Strand and the deployed cable position.

Today Bull Island is an important nature reserve, being a breeding site for many bird species and one of the most protected areas in Ireland.

The location was chosen as a test site due to the shallow sloping beach with wide intertidal zone. There are also few sand bars to form obstructions to nearshore access by small survey craft.

A series of boreholes, situated in St Mary's Golf Course, show the area to be underlain by a layer of soft silty sand, including occasional shell and gravel layers, with very stiff boulder clay below. The boreholes terminated at different depths ranging from 12.5m to 13.5m, suggesting either rock head or boulders.

Field Deployment

The data were collected using an Optasense ODH4 interrogator unit patched to a 1000m long armoured CST loose tube single mode fibre optic cable. The interrogator housed within a survey vehicle at the beach head. With the cable deployed from the beach using a work boat capable of operating in shallow water (Figure 2). The cable on the exposed sand was laid in a shallow trench to avoid interference from pedestrians. The DAS system was configured to acquire data using a 2m gauge length with Optical Channel Pitch (OCP) of 1m, effectively creating over 900 active channels spanning the beach, intertidal and marine zones. A hydrophone cable with 3.125m channel spacing, controlled by a Geonics Geode Seismograph, was deployed alongside the DAS cable in the nearshore zone to allow a direct comparison between the 2 sensor types.

A 12 cu in Sercel Mini G Airgun with a TAP Gun Controller was operated from an 8m long rib (gun boat) to provide the seismic source. A Gisco Radio Link was used to timestamp the DAS data with the T_0 trigger when the airgun was fired. The same system was used in parallel for triggering the seismograph when collecting hydrophone shot gathers. At low tide a sledge hammer/plate source was also used to provide a direct comparison between land and offshore SW data.

In this geological setting the chosen source was found to effectively generate surface wave data along the full length of the deployed fibre.

Figure 2 : Schematic representation of the cable deployment

Data Analysis

The real time depiction of the DAS data, known as a waterfall plot, was monitored to assess noise and data quality. Figure 3a represents a 20 minute portion of the recorded DAS data showing the marine portion of the cable (0 – 900m) and the beach section (900 – 1000m) where increased noise from people and vehicles on the beach are observed. Individual footfall on the beach portion of the cable can be clearly identified on the 30 second record (Figure 3b).

As well as showing the relative timing of the shot records (red box) Figure 3a shows the propagation of water waves towards the shoreline (yellow line). These pressure waves can be seen to slow down as they travel into the shallower water before breaking on the shore.

Figure 3 : Example DAS plots. a) 20 minute record (1000 channels), b) 30 second record (1000 channels) and c) 5 second record (500 channels).

Figure 4 : Processed SEGY shot record extracted from DAS data (Figure 3c).

Figure 5 : Dispersion curves for a) DAS, b) hydrophone (high tide) and c) geophone data (low tide)

SEGY shot gather data were extracted from the DAS dataset and filtered to remove the very low strain component. The data were displayed as shot gathers and analysed using the Surfseis MASW processing software to generate dispersion curve plots. These plots of phase velocity against frequency were used to assess the frequency – wavelength distribution and to compare the DAS acquisition to both hydrophone and geophone datasets (Figure 5).

All three sensor types showed good quality data with clearly resolvable dispersion curves. There is good correlation between the different sensors within the 10Hz to 25Hz Range with the DAS higher end frequency content being slightly limited due to the gauge length averaging that takes place in the DAS acquisition. At lower frequencies the level of uncertainty was reduced in the DAS data as a result of the increased number of channels and longer offsets possible due to the relative cable lengths.

Conclusions

The use of Distributed Acoustic Sensing (DAS) has proved effective at collecting shallow marine seismic data for analysis using the Multichannel Analysis of Surface Waves (MASW) method. The method has great potential due to the rapid data acquisition compared to other currently available technologies. It is expected that future developments in both the interrogator hardware and in more sensitive cable variants will address any limitations that exist with regard to high end frequency resolution.

Future planned work within this research project includes the collection of fibre optic data at offshore locations with increased water depth up to 50m, to determine the feasibility of DAS as a tool for geotechnical investigations for renewable energy projects.

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