Deterministic Comparison of DAS Field Data Against Physical Response Models of Subsea Cable Behaviour

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Abstract

Distributed Acoustic Sensing (DAS) is a novel technique for measuring strain in a fibre optic cable using laser light that is finding new applications in the subsea cable industry. In the future, Aurora Offshore Engineering may be able to use DAS to provide real-time monitoring of subsea cable motion and estimate cable reliability and lifetime. Firstly, however, DAS data must be shown to accurately reflect the physics of subsea cable motion. The motion of a subsea cable depends on metocean conditions such as tide and wave strength, and its physical properties such as its tension, diameter, mass, winding pitch, material, and the length of the spans that form between adjacent high-points on the seabed. This project aims to find the relationship between these quantities and the observed strain of the cable as a function of time and position and supported by field data, including metocean conditions and site surveys.

1. Introduction

A common statistic quoted in the offshore wind industry is that while subsea cables make up only 10-15% of project costs, they comprise over 80% of insurance claims (Klimczak 2023; Maloney 2024). This means that predicting and preventing subsea cable failures is one of the most important tasks in the future of offshore wind.

Currently, visual inspection using a remotely operated vehicle (ROV) is required to assess cable condition. Distributed acoustic sensing (DAS) may be able to replace this method with passive sensing of cable condition and provide further insights into the causes and probabilities of subsea cable failures. However, this application of DAS is still in an experimental phase in industry, and lacks empirical evidence of its accuracy in reflecting deterministic subsea cable physics. This project aims to assess the viability of using DAS to monitor subsea cables by finding the relationships between the strain signals found in historical DAS data and the physical response properties of subsea cables.

On the left of Figure 1 is a still from ROV footage as it was deliberately caused to bump into the subsea cable. The corresponding DAS data from the disturbed section of cable is shown on the right. The first goal of the project is to correlate the properties of the bump signal, such as frequencies, amplitudes, and decay rates, with the properties of the cable, such as the length of the free-floating span that was bumped, and the cable tension and dimensions.

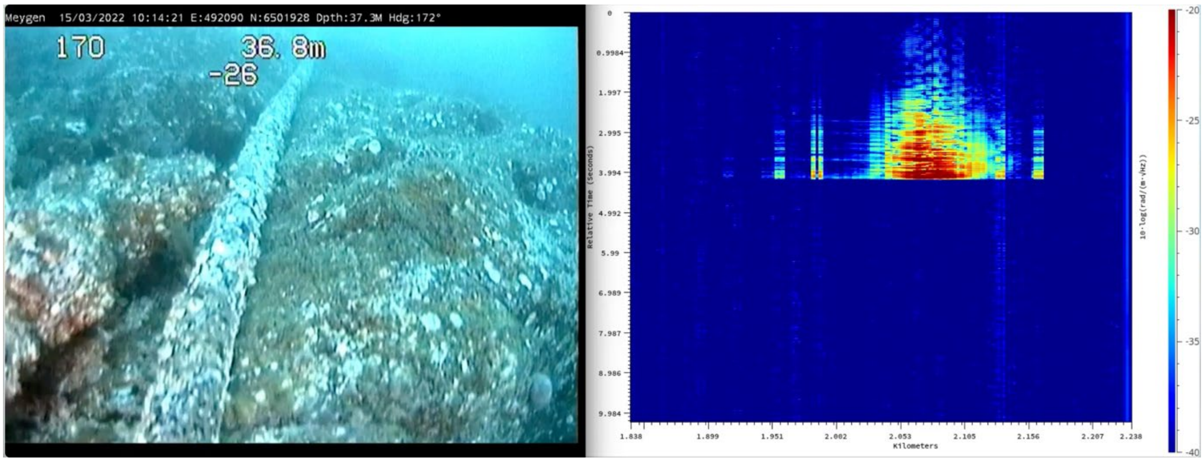

Figure 1 Left: footage from the ROV as it repetitively bumps into the cable.
Right: corresponding DAS strain data in the time - distance domain

The second goal of the project is to correlate the DAS signals with historical metocean data for waves, tides, and currents in the Pentland Firth during the DAS sensing period. This will help Aurora gain an understanding of the motion and fatigue of subsea cables due to metocean conditions. For example, the amplitude of the DAS signal should correlate with the strength of the current buffeting the cable. This is especially relevant because the cables are located at a tidal stream energy site that was chosen for its high speed flow.

1.1 Background

1.1.1 Distributed Acoustic Sensing

Distributed acoustic sensing is a type of distributed fibre optic sensing in which the fibre optic cable embedded in the power cable bundle is used to measure the strain along the cable (Zhan 2019). Laser light is shone down the fibre optic cable using a device called an interrogator. By analysing the Rayleigh backscattering of the light that is reflected back to the interrogator, deviations from the original length of each section of the cable can be measured (Nakazawa, 1983). Cable strain can be individually sensed for sections of cable that range between 2 and 40 m long, and for fibre optic cables up to 50 km in length. Axial strain of the fibre optic cable can be measured down to a nanometre (Waagaard 2022).

DAS interrogators have been shown to sense seismic events in both underground and subsea fibre optic cables. One of the most widespread applications of DAS is real-time sensing and prediction of earthquakes (Fernández-Ruiz 2022, Zhu 2023). Other possible applications of DAS include rail and highway sensing, military surveillance, and ocean sound monitoring.

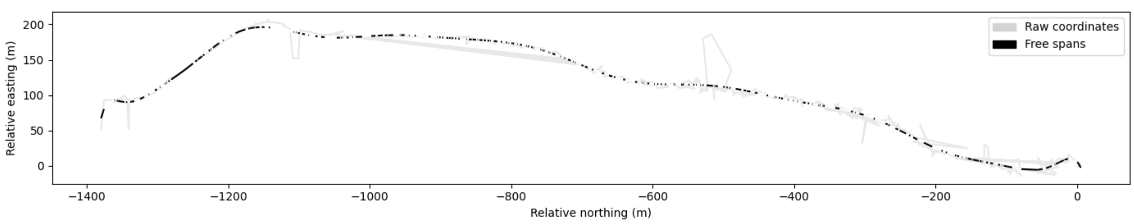

Figure 2 Smoothed cable map generated from the video analysis

1.1.2 MeyGen Tidal Energy Project

The DAS data that will be analysed in this project was collected in the cables of the MeyGen Tidal Stream Energy Project, located off the coast of Inner Sound, Pentland Firth, Scotland. This project is owned by SAE Renewables and began construction in 2015. Currently, two of the four turbines are fully operational. As of March 2023, over 51GWh of renewable energy has been generated (Tethys 2024).

Each of the four turbines are connected to the mainland of Scotland by subsea cables that are deployed directly over the bedrock and contain fibre optic cables capable of DAS interrogation. MeyGen worked with Alcatel Submarine Networks to interrogate the cables using their OptoDAS product (ASN 2024), over a three-week period in March 2022. Analysing this data is the focus of the project.

2. Process

2.1 Video Analysis

The first task in this project was to gather information about all the ROV bump instances from the footage, pictured in Figure 1. The ROV was flown along the cable from the turbines towards the shore under quiescent metocean conditions during slack tide. There were 109 recorded bump instances over roughly one hour. A python script was developed that used optical character recognition (OCR) to record the information in the header of the video whenever certain keys were pressed. The time and location of the bumps were recorded, along with a manual estimate of whether the cable was free-spanning in the water or supported by the seabed. The eastings were fitted with a 20-degree polynomial to the northings to create a smoothed cable map, pictured in Figure 2. The straight-line distances between each free-spanning or supported data points were calculated to estimate the lengths of all the free-floating spans.

2.2 Data Compression

The DAS strain data corresponding to the ROV survey totalled 770 GB and was stored on an external hard drive in HDF5 files. A python script was developed to load the DAS data in chunks, resample the time-series strain data to a resolution of one-millisecond, and store the data in NumPy files. The resampled data totalled 18 GB and could be more easily manipulated for data analysis.

2.3 Plotting Bump Instances

The strain induced in the cable by each ROV bump was plotted in the time, frequency and distance domains. Figure 3 shows a single bump instance on a 2D colormap in the top left, with time on the y-axis and horizontal distance on the x-axis, measured in discrete segments of the cable named channels. Each channel is a 1.02 metre long segment of the cable and corresponds to a single DAS strain measurement. There was a total of 109 bump plots generated.

The time-domain signal is the sum of the three channels centred around the channel exhibiting maximum strain at the bump instance. The signal is curve fit with an exponential to estimate the time decay constant for each bump. The maximum strain value is also recorded for each

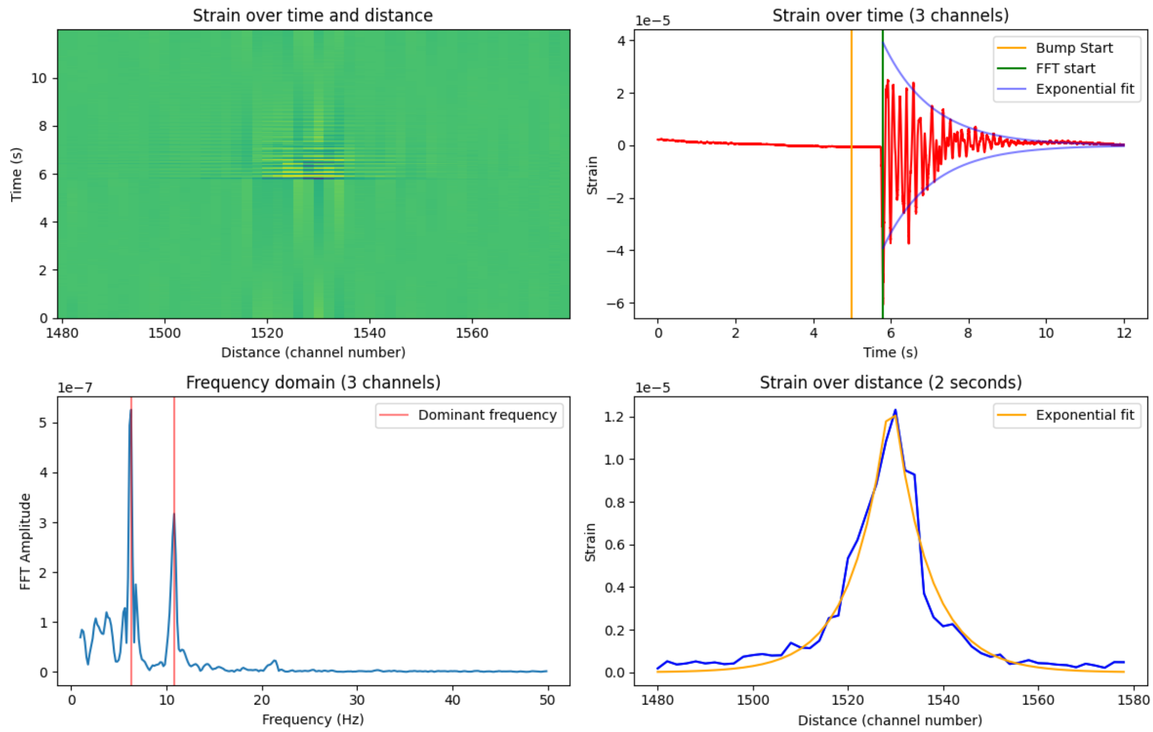

Figure 3 Top left: DAS strain in the time and distance domain
Top right**:** the same strain signal in the time domain
Bottom left: FFT of the strain signal in the frequency domain
Bottom right: the same strain signal in the distance domain

bump. The Fast Fourier Transform (FFT) is then applied to the time-domain signal, and the two tallest peaks are recorded as the dominant frequencies for each bump.

Finally, a horizontal slice is taken from the 2D DAS data, centred around the moment of max strain, and summed to produce a strain signal in the distance domain. This signal is fitted with two mirrored exponential curves to estimate the distance decay constant for each bump.

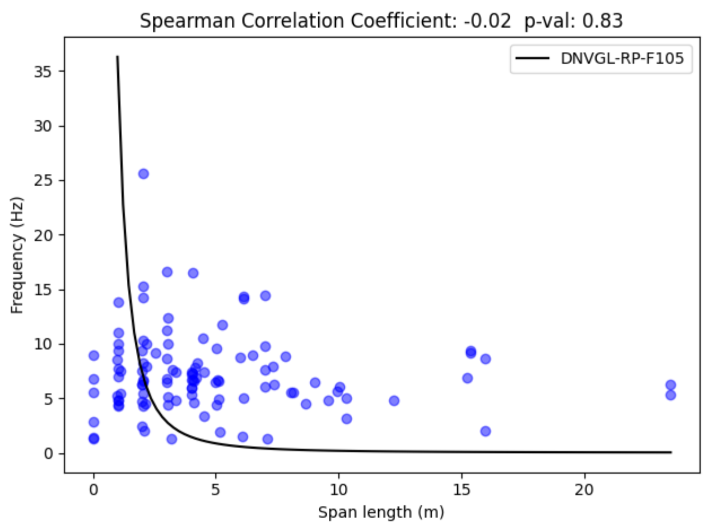

Figure 4 Scatter plot of frequency and estimated span length (from video analysis) for all ROV bumps.

3. Results and Discussion

The dominant frequency extracted from the FFT and the estimated span length extracted from the ROV footage were correlated and displayed on a scatter plot in Figure 4. With a spearman correlation coefficient of -0.02, there is currently no evidence of correlation between the two quantities. Also plotted is the fundamental frequency equation for free-spanning pipelines given in DNV-RP-105 (DNV 2017), which is a recommended practice published by DNV, an independent advisor for the maritime industry in assurance and risk management. There is no clear evidence that the data follows this trend. The other physical quantities that were collected for each bump were max strain, time decay constant and distance decay constant. To date, no significant correlations have been found between any of these quantities.

4. Conclusions and Future Work

The DAS strain data clearly identifies the timing and position of each ROV bump. Each measured DAS response varies significantly in characteristics and apparent quality. Some of the signals (such as in Figure 3) show qualitatively excellent behaviour, for example, well-defined dual peaks in the frequency spectrum and clear exponential decay in both time and space. There is currently no evidence that the DAS strain data is reflecting the existing physical response models of subsea cables. Seeking physical explanations for the apparently unexplained DAS response data remains the focus of the remainder of this project.

The manual estimation of cable span lengths from the ROV footage is a major limitation in this project. In future, more accurate span data may be acquired through photogrammetry methods and 3D modelling of the subsea cables.

Still to come in this project is an analysis of the relationship between DAS strain and the metocean data, for example, the strength of the current that is buffeting the cable over time. The metocean data is being transferred from SAE Renewables to the client on a hard drive and is expected to arrive in Perth during this semester.

5. Acknowledgements

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