Capturing The Effects of Remedial Trenching through Acoustic Imaging

M. Noel & S. Griffiths
Kraken Robotics, Aberdeen, UK

J.Y. Guigné
Kraken Robotics, St. John's, CA

Abstract
When remedial trenching occurs on a buried cable, is it truly known and understood what happens to the cable? Does the cables depth of lowering increase as desired, and is there any potential issues introduced to the buried cable? Previously, any results that varied from the expected had to be accepted and guessed as to why the change occurred without truly understanding the reasons why or they were simply confirmed as being unlikely. In this example, to accurately capture the effects of remedial trenching, a volumetric multiple acoustic aspect image of the remedial trenched sections of 40 cables, with a combined distance of 14.076 km was acquired. This revealed the characteristics and interactions within the shallow soils both before and after remedial trenching occurred, which found on average that a 0.1 m increase in cable depth was achieved. However, it was found that remedial trenching also has the potential to introduce new issues with the buried cable.

1 Introduction
Remedial trenching is an important aspect when installing subsea cables and it is a common practice around the world. This is due to when a subsea cable is installed, there is a target depth of lowering (DoL) that must be achieved to ensure the cable remains buried and protected. If sections of the cable or all the cable are not at the target depth, there are two options which can be used to try and achieve the target cable DoL. The first is to lay a stabilising feature, such as a rock dump or cement mattresses, on the seafloor above the cable. The other is to perform remedial trenching on the cable, which is where the cable undergoes another phase of trenching to try and excavate more sediment under the cable in an attempt to bury the cable further. The choice of the method is dependant on several factors, which vary depending on the cable and environment. Regardless of the method used to try and increase the DoL of a subsea cable, the measurement of the depth usually comes from one of two sources; the recorded depth of the trenching sword and/or magnetics. The issue with either of the commonly used methods, which determines the depth of a cable after trenching, is that there are several uncertainties and assumptions accepted. However, when it comes to performing remedial trenching, we need to review the results with an external piece of equipment which captures the entire picture of the remedial trenching to eliminate the uncertainties and remove all the assumptions.

Over the past few years, Kraken Robotics (formerly PanGeo Subsea) has been involved in several projects which required the imaging of buried cables prior to and after remedial trenching occurred. This has allowed the effects of remedial trenching to be assessed across different geological settings, different trenching tools and different cable properties.

2 The Technology Used and How It Works

The technology that was used for all the cable detections and analysis work was the volumetric multiple acoustic imager known as the Sub-Bottom Imager™ (SBI). The SBI is considered a new class of sub-bottom inspection tool, where it uses acoustics rather than the industry go to of magnetics (Dinn, 2012). The rendering of the SBI image is processed by successive acoustic signals being transmitted to "illuminate" a buried target, and the reflection of each transmitted signal is received and recorded. The SBI is able to deliver positionally accurate subsea imagery of the buried cables due to its signal transmission, which is arranged by broad beam projectors with the beam pattern aligned with the swath. To improve the along-track resolution, the SBI uses synthetic aperture technology to increase the number of traces captured on a target. The transmitted signals that are reflected back to the array are detected by a 40 sensor/hydrophone array, which are aligned in an across-track direction. The transmitter and receiver array is continually moved forward where it emits acoustic signals in a distinct pulse manner in rapid succession which translates into a volume of data visualising the seafloor and shallow soils beneath the receiver array. Thus, a sub-seafloor feature reflected signals are received from multiple multi-aspect views emanating continuously from the seafloor and the buried cable within the shallow soils. Additionally, the linear receiver array focuses on returning energy in the across-track (perpendicular) direction while at the same time, synthetic aperture processing yields the alongtrack (forward) focusing (Guigné, McDermott, & Noel, 2021).

The SBI imaging results in a continuous (three-dimensional) trapezoidal prism of data, where the data can be sliced and viewed in any domain (Figure 1). It can be thought of as a continuous ribbon of data which is a minimum of 5 m wide at the seafloor (with a flyheight of 3.5 m), approximately 5 m depth below the seafloor, and infinitely long (Guigné, McDermott, & Noel, 2021).

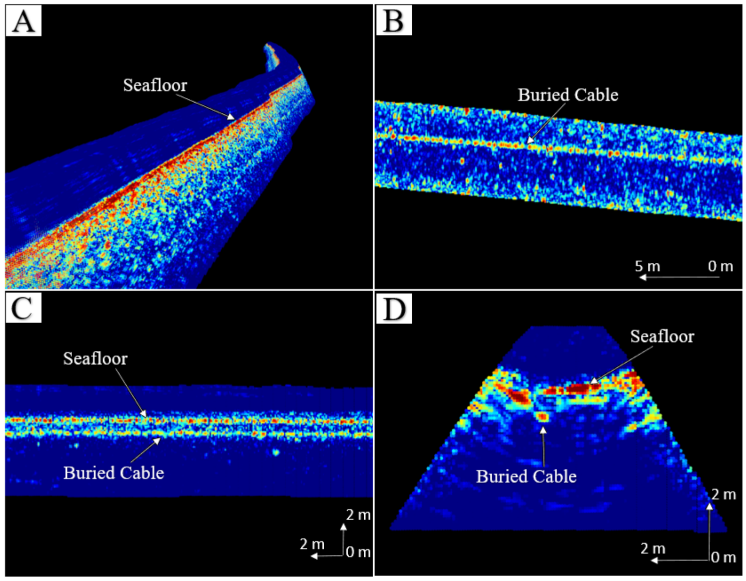

Figure 1. Typical SBI data over a buried cable. A) 3D volumetric data stream, capturing the X,Y,Z domains. B) Plan view capturing the X and Y domains C) Along track view capturing the X and Z domain. D) Across track view capturing the Y and Z domains

3 Geological Conditions, Trenching, and Survey Parameters

3.1 *Geological Conditions*

The data which was analysed corresponds to 40 sections of different buried cables, two of which have data for a second phase of remedial trenching. The geological settings of each cable have been classified into three distinct categories (Table 1): 1) Homogenous sands 2) Heterogeneous sediments 3) Deltaic sediments. The homogenous sand corresponds to sediment which is comprised of clean, medium to high density sand with little to no presence of gravel, cobbles or lithics. In this sediment type there was no observed geological layering, visible changes in density, or obstructions to the trenching operations. The heterogeneous sediment is comprised of mainly sand with the presence of boulders and interbedded clay, possibly representing glacial till. Within the SBI data there are observed discrete anomalies (interpreted to be boulders), however they present no clear effect on the trenching operations. As seen within Figure 1, the cable is trenched and buried within heterogeneous sediments where the presence of cobbles/gravel have no clear impact on the trenching operations. The final geological setting category is the deltaic sediments, which have the characteristics of a deltaic depositional environment where there is clear lithological layering observed. The higher the amplitude of the reflectors observed within the data, it is possible that these relate to dense lithological layers that may have required a greater amount of force to trench through.

3.2 *Trenching Parameters*

There were two types of trenching techniques which were used for both the original and remedial trenching operations (Table 1). The first was a remotely operated vehicle (ROV) with a water jet trenching tool. All but one cable used this technique and this is the most common technique that has been observed. It must be noted that a larger, more powerful trencher carried out the remedial work on the heterogenous sediments due to the trencher availability at the time of the installation phase of the subsea cables. A larger, more powerful trencher may have improved the success rate of achieving the target cable DoL. The other technique that was used for only one cable was the mass flow excavation system. This technique involves using a crane to deploy the tool off the side of the vessel where it works in a similar way to a pressure washer and uses a high-pressure water jet to remove the sediment underneath the cable.

In all the cable sections which underwent remedial trenching, the target cable DoL was a minimum of 1.5-2 m, depending on the location of the cable. In all cases the entire surveyed section was measured to be less than the required cable DoL. The final results from the survey concluded that for all cable sections analysed, none had achieved the minimum DoL.

3.3 *Installation Parameters*

The subsea cables had one of the following installation parameters (Table 1); where it was either installed to a wind turbine generator (WTG), or it was not installed to a WTG. For both types, there was sufficient excess cable available at both ends of the cable in preparation for any possible remedial trenching.

3.4 *Survey Parameters*

All the cables were surveyed under the same conditions, which involved the SBI equipment being mounted onto a remotely operated vehicle (ROV) and operated within the required specifications of the equipment. All the analysed data were tidally corrected to ensure all the comparisons were completed to the same vertical datum, which eliminated any possible depth discrepancies between SBI datasets, which in turn prevented any influence on the results.

4 Overall Results of Change in Cable Depth

Forty different sections of cable, which underwent remedial trenching along with two sections, which underwent a secondary phase of remedial trenching were analysed and compared to determine the minimum, maximum, and average change in the cable depth (Table 1). From these values the overall weighted average, taking into account the length of the cable section compared to the overall length of all analysed results (14.076 km), found that remedial trenching increased the cables depth by 0.10 m. It was found that the more homogenous the shallow soils were, the greater the cable depth increase was after remedial trenching (Table 2). For shallow soils with increasing complexity, remedial trenching was found to not increase the cable depth and instead the trench where the cable was located was observed to become wider, not deeper as desired (Figure 3).

Table 1. Summary of the geological environment, the cable installation parameters, and the type of trenching technique used for the remedial trenching for each cable. Cable IDs with A/B representing sections of cable which have undergone a second phase of remedial trenching.

Cable ID	Geological Setting	Installed to WTG	Trenching Technique	Length (m)	Min Depth Increase (m)	Max Depth Increase (m)	Average Depth Increase (m)
1	Homogeneous	Yes	Water Jet	399	-0.2	0.2	0.03
2	Homogeneous	Yes	Water Jet	137	-0.3	0.3	0.03
3	Heterogeneous	Yes	Water Jet	177	-0.3	0.1	-0.02
4	Heterogeneous	Yes	Water Jet	225	-0.3	0.7	0.31
5	Heterogeneous	Yes	Water Jet	425	-0.1	0.2	0.03
6	Heterogeneous	Yes	Water Jet	120	-0.1	0.3	0.05
7	Heterogeneous	Yes	Water Jet	285	-0.1	0.3	0.11
8	Homogeneous	Yes	Water Jet	100	-0.9	0.1	-0.16
9	Heterogeneous	Yes	Water Jet	134	-0.1	0.1	0.02
10A	Homogeneous	Yes	Water Jet	523	-0.6	0.3	0.01
10B	Homogeneous	Yes	Water Jet	533	-0.2	0.4	0.03
11	Homogeneous	Yes	Water Jet	145	-0.2	0.3	0.03
12	Homogeneous	Yes	Water Jet	80	-0.2	0.3	0.03
13	Homogeneous	Yes	Water Jet	147	-0.2	0.4	0.03
14	Homogeneous	Yes	Water Jet	919	-0.2	0.6	0.10
15	Homogeneous	Yes	Water Jet	821	-0.2	0.7	0.09
16	Homogeneous	Yes	Water Jet	705	-0.2	0.3	0.04
17	Homogeneous	Yes	Water Jet	160	-0.1	0.4	0.17
18	Homogeneous	Yes	Water Jet	132	-0.2	0.3	0.01
19	Homogeneous	Yes	Water Jet	747	-0.2	0.4	0.08
20	Homogeneous	Yes	Water Jet	115	0	0.2	0.04
21	Homogeneous	Yes	Water Jet	560	-0.1	0.7	0.14
22	Homogeneous	Yes	Water Jet	78	-0.2	0.7	0.36
23	Homogeneous	Yes	Water Jet	290	-0.4	1.3	0.45
24	Homogeneous	Yes	Water Jet	159	-0.1	0.6	0.24
25	Homogeneous	Yes	Water Jet	102	-0.1	1.2	0.32
26	Homogeneous	Yes	Water Jet	82	-0.1	0.3	0.08
27	Homogeneous	Yes	Water Jet	122	-0.1	0.3	0.08
28	Homogeneous	Yes	Water Jet	950	-0.3	1.1	0.05

Cable ID	Geological Setting	Installed to WTG	Trenching Technique	Length (m)	Min Depth Increase (m)	Max Depth Increase (m)	Average Depth Increase (m)
29	Homogeneous	Yes	Water Jet	110	-0.2	1.7	0.66
30	Homogeneous	Yes	Water Jet	240	-0.1	0.7	0.29
31	Heterogeneous	Yes	Water Jet	163	-0.1	0.4	0.23
32	Heterogeneous	Yes	Water Jet	140	-0.1	0.3	0.03
33	Heterogeneous	Yes	Water Jet	346	-0.2	0.2	0.06
34	Heterogeneous	Yes	Water Jet	133	0	0.2	0.09
35	Heterogeneous	Yes	Water Jet	108	-0.1	0.1	0.20
36	Heterogeneous	Yes	Water Jet	709	-0.1	0.2	0.00
37	Homogeneous	Yes	Water Jet	815	-0.2	0.7	0.19
38	Heterogeneous	Yes	Water Jet	750	-0.2	0.7	0.02
39	Heterogeneous	Yes	Water Jet	53	-0.2	0.2	-0.01
40A	Deltaic sediment	No	Mass Flow	640	-0.5	0.5	0.02
40B	Deltaic sediment	No	Mass Flow	500	0	0.5	0.27

Notes: For each cable section, the change in the cable depth for before and after remedial trenching occurred was measured every metre along the cable section. From this the minimum, maximum and overall average in the change of cable depth was calculated. Positive values represent an increase in depth while negative values represent decrease (shallowing) in depth.

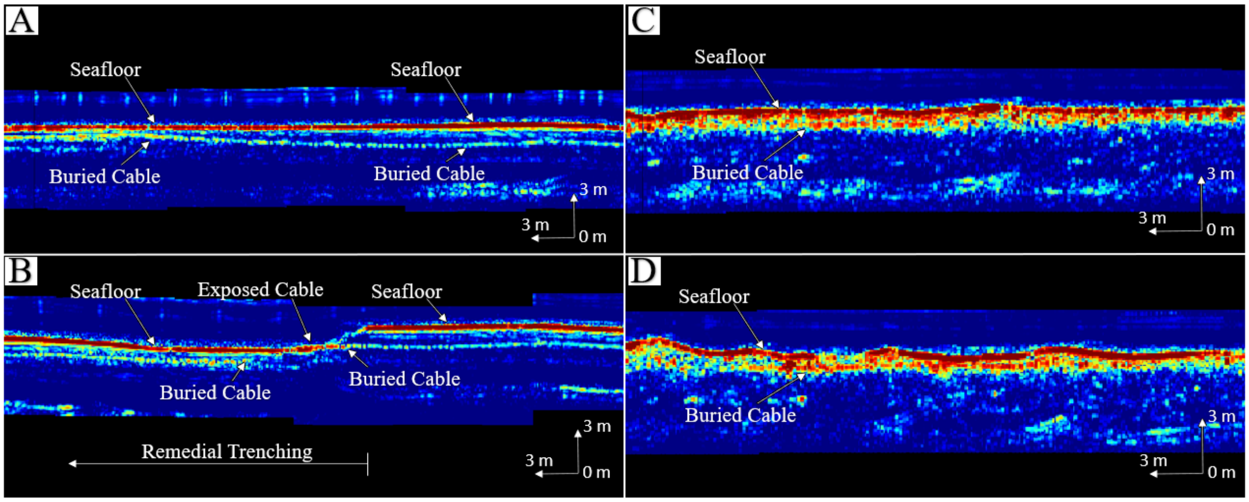

Figure 2. Before (A) and after (B) data examples of remedial trenching in homogeneous sand and before (C) and after (D) data example of remedial trenching in heterogenous sediment. A and B is showing the section of remedial trenching with the largest increase in cable depth from the analysis. C and D is showing the section of remedial trenching with the smallest increase in cable depth from the analysis.

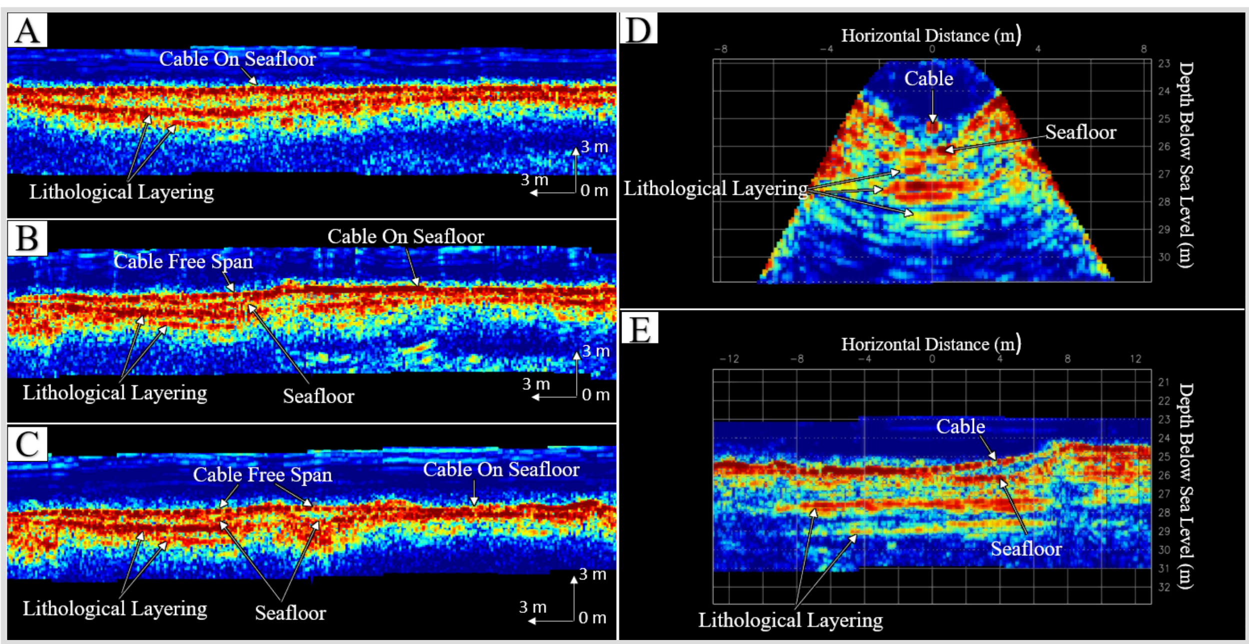

Figure 3. Data examples of a cable in deltaic sediments, Cable 40. Originally trenched cable (A), cable following remedial trenching (B), and second phase of remedial trenching (C), (D) and (E). These data examples are highlighting areas of the cable where free spans were introduced through remedial trenching in the cross-track and along-track views, respectively.

Table 2. Summary of calculated results depending on the different variables between each survey

Variable	Weighted Average DoL Change (m)
Homogeneous Sand	0.11
Heterogeneous Sediment	0.06
Delta Sediment	0.13
Installed to WTG	0.09
Not Installed to WTG	0.13
Water Jet ROV	0.09
Mass Flow Excavation	0.13

5 Potentially Introduced Issues Through Remedial Trenching

With each interaction with a subsea cable, there comes the potential of introducing issues to the cable. Through being involved in the investigational stages of different subsea cable DoL surveys, it has been possible to capture and observe the two most common introduced issues from remedial trenching. These are introducing cable free spans span and physically damaging the cable and/or cable bundle.

5.1 *Introduction of Exposure and Cable Free Span*

When remedial trenching occurs, the cable becomes temporarily exposed in the water column with the aim to have the cable become buried again through backfill and sediment deposition. However, prolonged exposure leading to cable free span is possible. Cable free span is when a cable is situated above and separated from the seafloor, (Figure 4). In homogeneous sand, cable exposures and cable free spans frequently occur at the transition points where the remedial trenching starts and ends (Figure 2). In both heterogeneous and deltaic sediments, the potential of exposures and/or cable free span can occur through the entire remedial section. It was observed during Cable 40 remedial trenching work, that the more phases of remedial trenching that took place, the more cable exposures and cable free spans were introduced. This is a result of the cable remaining stationary on a dense lithological layer or when there is not enough excess/too much tension in the cable and the trencher removes the softer sediment below the cable. Depending on the rate that sediment will fill this void, the cable has the potential of being exposed and vulnerable to the elements for a prolong period where the risk of cable damage or failure is increased. Also, it is important to note that when cable exposures/free spans occur, the overall depth of the cable does not increase. Therefore, even though the trencher is reporting an increase in trenching depth, when the cable finally becomes buried again through either backfill or sediment deposition it will still not meet the minimum required DoL.

5.2 *Damage to Cable and/or Cable Bundle*

In a worse case scenario, it was observed that a previously buried cable bundle was split apart as the excess cable had been pushed towards/focused to one location and forced upwards above the bottom of the open trench where each cable was then put into free span (Figure 4). The remedial trenching campaign on the example below did not achieve an increase in the cable depth as it was situated within a heterogenous soil where the original trenching operations placed the cable on a dense geological layer. If an acoustic survey were performed prior to the remedial trenching commencing, this information could have potentially been provided. Using the acoustic data, it may have been possible to show that remedial trenching would have most likely not achieved an increase in the cable depth, therefore preventing cable damage from occurring.

Another type of damage that has been observed is a cable becoming crushed through remedial trenching from opposing directions on a bend in the route. There was no increase in the cables depth during the remedial trenching, therefore similar to the example in Figure 4, the cable excess became focused and compressed into the bend which resulted in the cable becoming crushed together and broken.

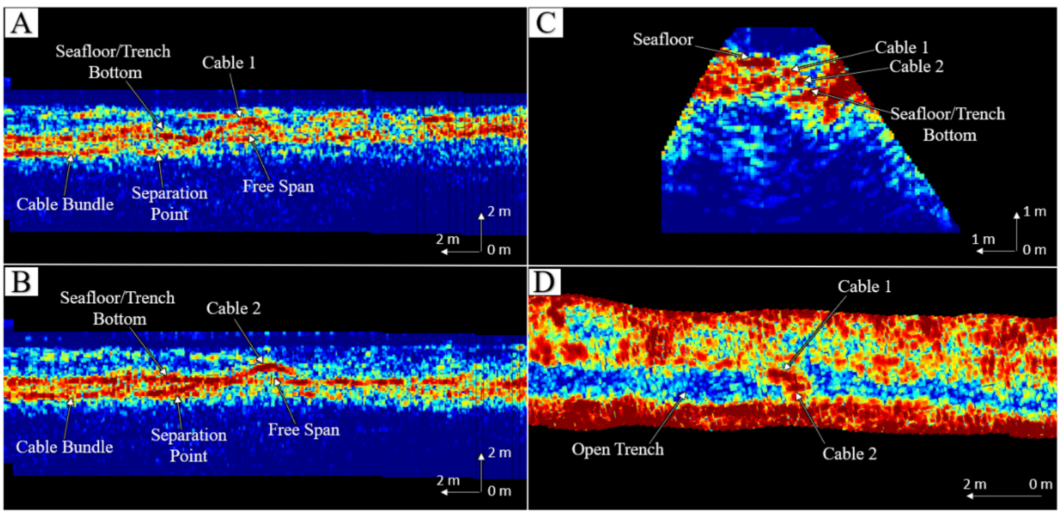

Figure 5. Data example of a cable bundle that has been split apart and pulled to the seafloor where each cable is observed to free span at the bottom of an open trench. (A) along-track view highlighting Cable 1. (B) along-track view highlighting Cable 2. (C) across-track view highlighting vertical and lateral separation of Cable 1 and Cable 2. (D) plan view highlighting the lateral separation of Cable 1 and Cable 2.

6 Conclusion

Through all of the analysis work it was observed that the only sediment type which showed a relatively high degree of change in the cable DoL was the homogenous medium to high density sand. In both the heterogeneous and deltaic sediments, the cable DoL was observed to be dependant on the lithological layers. Where the cable was resting on top of a dense lithological layer and even with numerous remedial trenching phases, the cable depth would not increase. A trend which was observed across all cable sections which underwent remedial trenching was the introduction of cable spikes. This is when the depth of the cable changes rapidly, which has the potential of creating points of failure or damage to the cable or cable bundle. Another trend which was observed in 39 of the cable sections was locations of the cable becoming shallower. The shallowing of the cable appears directly after and/or directly prior to a location in the cable which has a depth increase through remedial trenching. Best way to think of this is as a 'seesaw'; as one section of the cable becomes deeper through remedial trenching another section of the cable becomes shallower. This has the potential of putting sections of a cable that were in the required DoL specification, out of specification. If only the targeted location of remedial trenching is resurveyed following the completion of the remedial work, there is a potential of these sections that have become shallower than the target DoL going unnoticed. This in turn may lead to the cable or cable bundle becoming damaged and/or failing.

Through all the remedial cable surveys which Kraken Robotics have been part of, a common theme observed was that the geological complexity of the shallow soils is the major contributing factor to the final depth of a cable, rather than the ability of the trenching technique used. It is also determined by, and sometimes the major defining factor, the geological complexity of the shallow soils. Without a proper understanding of the sediment and the geological layering in the area and its relationship with the cable or the cable bundle, performing remedial trenching is putting the cable at risk of damage and/or not achieving the required DoL. The risk of potential damage introduced to a cable or cable bundle need to be weighed up against achieving a potential average of 0.1 m increase in a cables DoL.

6 References

Dinn, G. (2012). Field experience with a new sub-bottom investigation tool: Acoustic 3-D imaging of the sub-seabed. *Oceans*, 1-9.

Guigné, J. Y., & Blondel, P. (2017). Acoustic Investigation of Complex Seabeds. *Springer International Publishing*.

Guigné, J. Y., McDermott, I., & Noel, M. (2021). Multi-Aspect Acoustic Imaging of Buried Cables in Complex Seabeds. *First EAGE Workshop on East Canada Offshore Exploration.* St. John's, Canada: EAGE.