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Nova Innovation Ltd

Shetland Tidal Array

Cable Protection Risk Assessment

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1 Introduction

This document contains a navigational risk assessment of cable protection for the Nova Innovation Shetland Tidal Array. The document should be read in conjunction with the associated Cable Plan (CaP) for the array, which describes the array location and specification in more detail.

The structure of this document is as follows:

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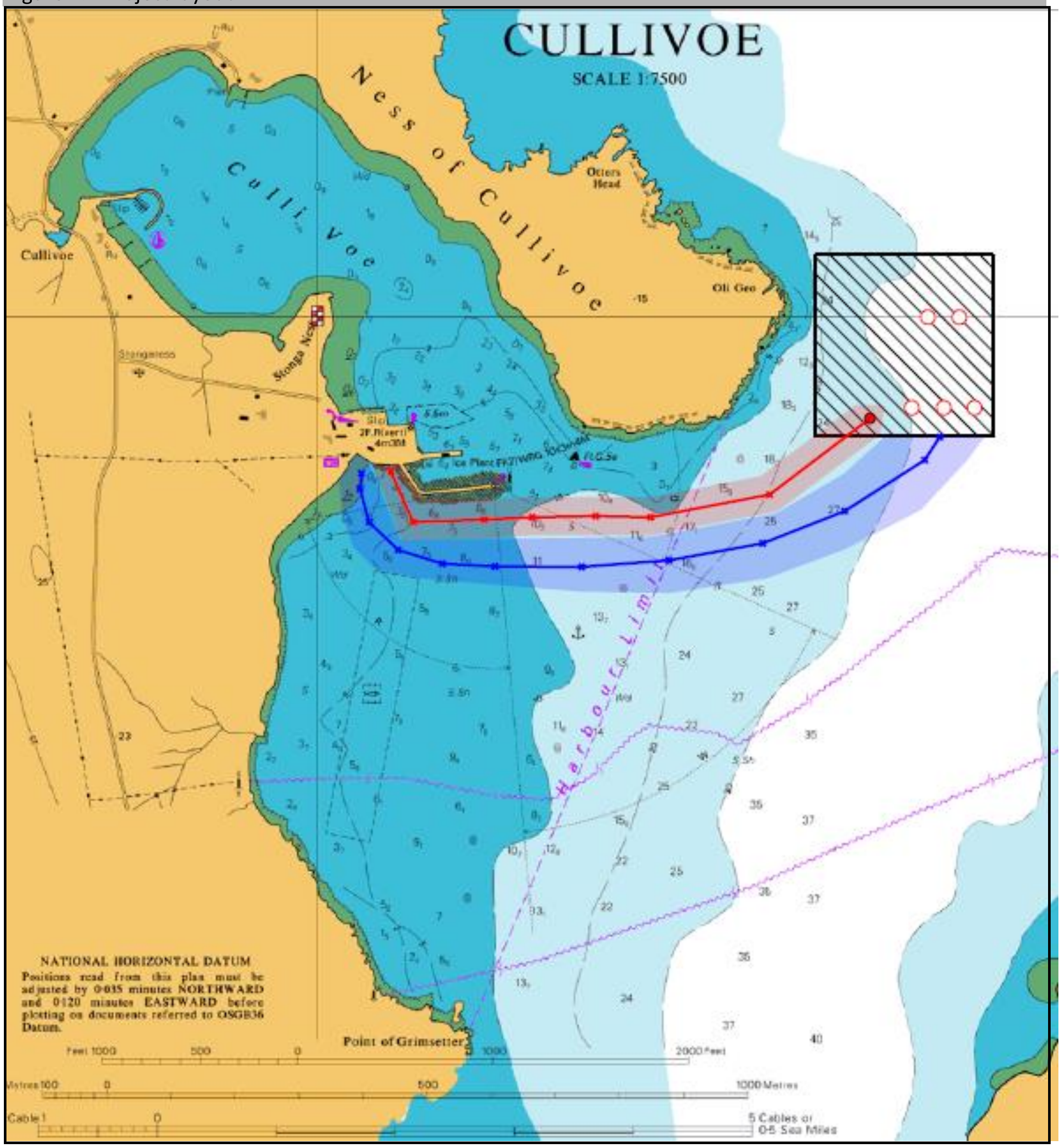
2 Project overview

Nova Innovation's Shetland Tidal Array will consist of five 100 kW turbines located in the Bluemull Sound in Shetland. The proposed location of the turbines and cables is shown in Figure 2.1.

- The lease area is marked by a hatched rectangle. Red circles illustrate the proposed location of the turbines.
- The solid red dot indicates the location of the existing Nova Innovation demonstrator turbine. The red line shows the path of the cable from this turbine to shore; the red shaded area is the Crown Estate lease area for this cable.
- The five array cables will follow the track of the blue line to shore, and will lie within a corridor indicated by the blue shaded area.

Figure 2.1 Project layout



Source: Copyright © Nova Innovation 2015, UKHO

2.1 Cable specification

Five individual cables will be laid, one from each device to shore. The length of each cable is in the range 800 to 1000 m depending on the location of the device within the array.

Each cable is a 3.3 kV 3 phase cable including two armour layers and a hard outer HDPE shell, bringing extra stability, robustness and electromagnetic shielding compared to alternative cable designs. The outer diameter of the cable is 48 mm.

2.2 Concrete mattresses

Concrete mattresses are commonly used to protect subsea cables and pipelines, particularly at their intersection, and as scour protection around subsea structures. They consist of a matrix of prefabricated concrete blocks connected by polypropylene rope. The installation of concrete mattresses typically requires diver intervention to assist with accurate placement (BERR 2008). It also involves significant surface operations and is not typically conducted in strong tidal streams. Concrete mattresses can each weigh up to 10 tonnes and a typical mattress would measure 5 m x 3 m x 300 mm thickness, though smaller and lighter mattresses are also available.

Figure 2.2 Concrete mattress being deployed over a pipe section

Source: FoundOcean Ltd

3 Navigational risks

Consultation on the CaP has identified three primary navigational hazards associated with the cables:

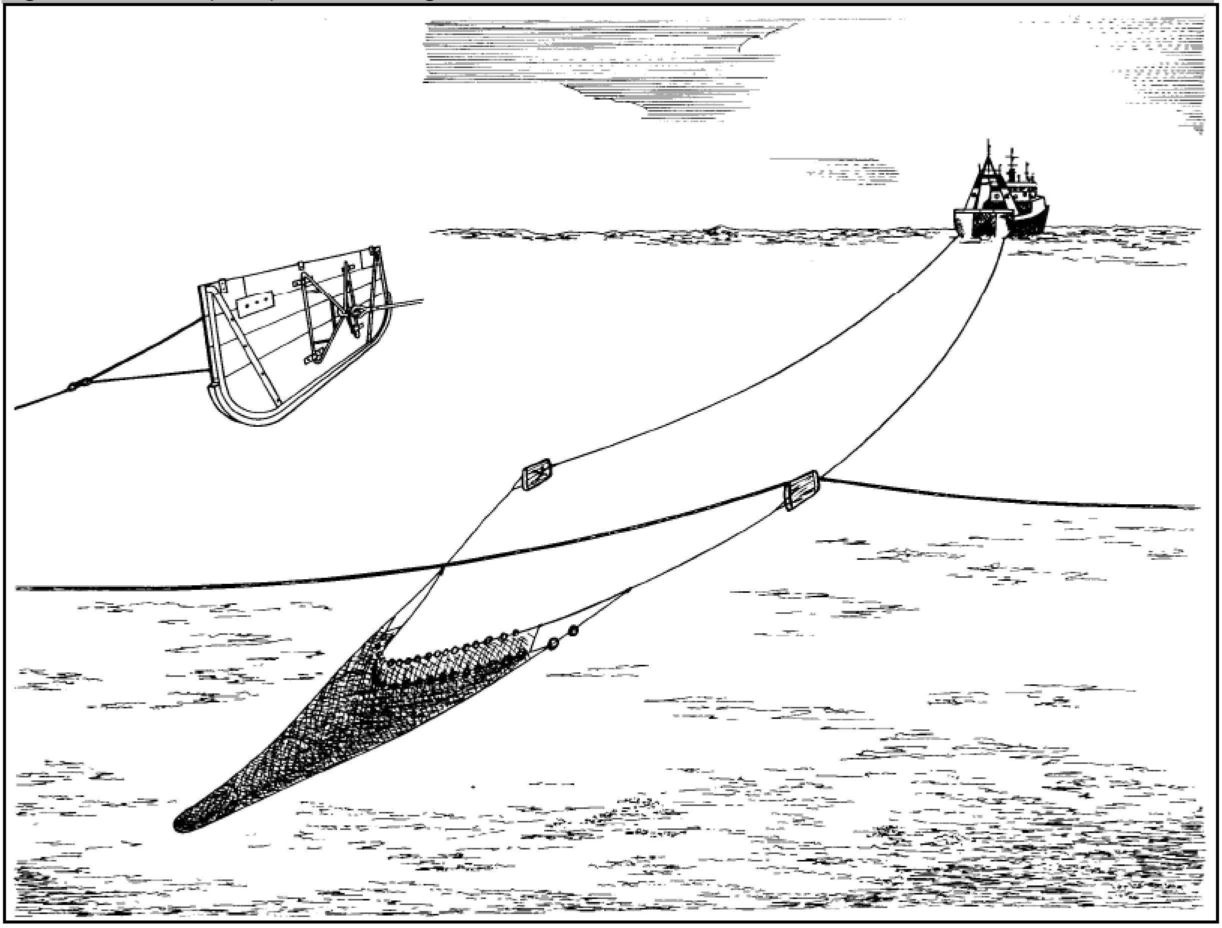
- Snagged fishing gear
- Snagged anchors
- Cable movement

These risks are considered below.

3.1 Snagged fishing gear

Fishing gear can snag on a cable, posing possible risks of electrocution and capsize. This can occur during operations like trawling or recovery of static fishing gear. Snagging is a common issue during such activities and experienced fishermen are well versed in unsnagging fouled gear; if this is not possible then the fouled gear will be discarded. In extreme situations snagging may lead to vessel capsize.

Figure 3.1 Bottom (otter) trawl catching cable



Source: ICPC 2009

3.2 Snagged anchors

Anchors can become snagged on cables, posing possible risks of electrocution and capsize. This can occur when an anchor is deployed in the region of a cable or when a deployed anchor drags and snags a cable. Attempts to recover the anchor can damage the cable and, in extreme cases, may lead to vessel capsize (ICPC 2009).

3.3 Cable motion

Cables can move under hydrodynamic forces from the waves and tides. This can potentially lead to cables moving away from charted location on the seabed, increasing the risk of accidental snagging as discussed above.

3.4 Severity

Snagging on cables (or any underwater object) either when fishing or with anchors could be hazardous to vessels. It can lead to cable damage and can in principle, in extreme cases, lead to capsize and loss of life (ICPC 2009). There is also a risk of electrocution from damage cables.

3.5 Legislative framework

In light of these risks, and because of the additional risk of damage to cables and associated costs, a system for reporting potential snagging events and compensating fishermen for loss of gear is in place[1]. Under the Submarine Telegraph Act 1885, it is a punishable offence to break or injure any submarine cable; wilfully or by culpable negligence. However, cable owners are obliged to compensate the owners of vessels if those owners can prove that they have sacrificed an anchor, net or other fishing gear in order to avoid damaging a submarine cable.

Kingfisher Information Services Cable Awareness (KISCA) charts are freely available, which identify all in-service cables and the associated cable maintenance company.

[1] http://www.subseacablesuk.org.uk/emergency-procedures/

4 Literature review

4.1 Review of Marine Accident Investigation Board reports

Statistics on the prevalence of snagging on subsea cables in UK waters were not available for this report. However, the Marine Accident Investigation Board (MAIB) maintains an on-line database record of 828 accident reports[2], spanning the period from 1987 to 2015. The MAIB investigates marine accidents involving UK vessels worldwide and all vessels in UK territorial waters. The reports cover all such recent accidents resulting in the loss or destruction of or serious damage to any ship or structure, the death of or serious injury to any person, or serious environmental damage.

A review was conducted of the 828 accident reports available on-line. From this database there were 23 reports selected using the search term "snag". These reports were reviewed for relevance to this risk assessment; 16 relevant reports are summarised below. An additional search conducted using the search tem "cable" did not reveal any additional relevant reports.

Table 4.1 MAIB review summary

Vessel	Year	Description	Outcome
Jubilee Star	2009	Trawler snags on an unknown obstruction.	**Vessel lost** **No fatalities**
Levan More of Looe	2008	Trawler snags fishing gear on an unknown subsea obstruction and sinks.	**Vessel lost** No fatalities
Guyona	2008	Scallop dredger snags fishing gear on rough ground	**Vessel lost** No fatalities
Misty Dawn	2008	Trawler snags fishing gear on unknown subsea obstruction.	**Vessel lost** No fatalities
Nordsee	2007	Container feeder vessel snags anchor on trenched 132kV subsea power cable.	Vessel undamaged **Cable damaged**
Young Lady	2007	Dragging anchor of large product carrier snags trenched subsea gas pipeline, damaging the pipeline.	Vessel undamaged **Pipeline damaged**
Harvest Hope	2005	Trawler snags fishing gear whilst trawling near to charted pipeline; likely to have fouled on boulder clay deposits created by the pipeline backfill trenching plough.	**Vessel lost** No fatalities
Bounty	2005	Trawler snags fishing gear on a subsea obstruction ("fastener"). Note from MAIB report: "Although neither the skipper nor the crewman knew what the fastener was, they were not unduly concerned as fasteners were encountered about once a week."	**Vessel lost** No fatalities
Boy Andrew	2004	Fishing vessel snags on unknown subsea obstruction.	**Vessel lost** No fatalities
Chelaris	2003	Trawler snags on sandbank. Notes from MAIB report: "Snagging occurred frequently when fishing on the bank"; "Snagging of fishing gear will inevitably occur when trawling."	**Vessel lost** **4 fatalities**
Radiant	2002	Trawler snags fishing gear, thought to be on a coral reef or potentially an uncharted wreck.	**Vessel lost** **1 fatality**
Sundance	2001	Trawler snags unexploded WW2 torpedo.	**Vessel lost** **1 fatality**
Westhaven	1997	Pair trawler snags on free span in unburied, charted subsea pipeline.	**Vessel lost** **4 fatalities**

[2] https://www.gov.uk/maib-reports

Heather Bloom	1994	Trawler snags on unknown obstruction and sinks with loss of one life. From MAIB report: "It is not unusual for a trawl to snag on a sea bed obstruction during this type of operation."	**Vessel lost 1 fatality**
Pescado	1991	Trawler gear snagged, likely on boulder.	**Vessel lost 6 fatalities**
Majestic	1991	Pair trawler snags unknown subsea obstruction "which is not uncommon in this type of operation", capsizes when trying to heave the net in.	**Vessel lost 5 fatalities**

Source: Marine Accident investigation Board

4.2 Incidents involving concrete mattresses

A web review was conducted in order to identify incidents involving subsea concrete mattresses.

Table 4.2 Web review for concrete mattress incidents

Project/activity	**Year**	**Description**	**Outcome**
Riffgat offshore wind farm	2013	Diver killed during concrete mattress deployment on submarine cables for German offshore wind farm.	**1 fatality**
Concrete mattress installation	2004	Diver injured during concrete mattress installation (IMCA 2004)	Diver injury
Concrete mattress installation	2001	Near miss to diver during concrete mattress installation (IMCA 2001)	Near miss
Concrete mattress installation	1999	Crane whip line parted during concrete mattress lift on offshore vessel	Near miss
Concrete mattress installation	1997	Diver injured in the North Sea during mattress deployment (Bonomy 2003)	1 injury

Source: Nova Innovation web research

4.3 Snagging on concrete mattresses

A web review identified no instances of fishing vessels or anchors snagging on concrete mattresses. However, we note the following statement in a report commissioned by Zero Waste Scotland and Decom North Sea on the decommissioning of concrete mattresses (Jee 2015):

> *mattresses can present a significant snagging hazard to trawlers*

This is supported by the response of Hartlepool Fishermen's Society to the planning proposal for Dogger offshore windfarm[3], which proposed using concrete mattresses for cable protection:

> *Both these forms of cable protection [rock dumping and concrete mattresses] are likely to present a significant marine hazard to under-10m trawlers, as they present an obstacle upon which fishing nets can be easily caught.*

It is clear from these comments that the use of concrete mattresses (or rock dumping) does not eliminate a snagging threat.

4.4 Cable stability and hydrodynamics

A common source used when determining cable design stability is DNV standard RP-F109: *On-Bottom Stability Design of Submarine Pipelines* (DNV 2010). As the name implies, this standard has been developed to assist the design of pipelines and not cables. In addition, the focus of the standard is on sand and clay sea beds, and not the rocky conditions common to many tidal sites. The empirical relationships and industry experience embodied in the standard have not been proven to be relevant for cables at tidal sites, and therefore should be applied with a degree of caution; however this is the commonly accepted standard used to determine cable stability.

3

The forces acting on by a subsea cable in a tidal stream are illustrated in Figure 4.1. The cable experiences an inertia force from fluid acceleration and a drag force that is proportional to the square of the fluid velocity. Asymmetric flow over the top of the cable creates a pressure difference which results in a lift force, which is also proportional to the square of the velocity. Acting against these forces is the resistance of the sea bed, which is proportional to the net downward force from the cable (cable weight less buoyancy and lift).

Figure 4.1: Force diagram for a subsea cable

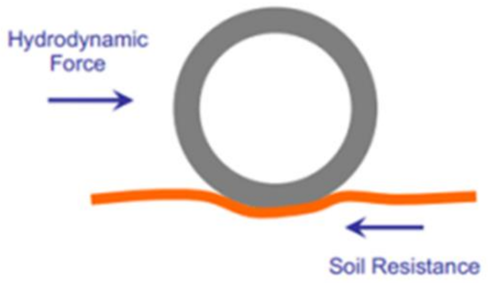
$$\mu(W_s - F_L) \geq (F_D + F_I)$$

Where,

$F_L = \frac{1}{2} \rho_w D C_L V^2$ Lift Force

$F_D = \frac{1}{2} \rho_w D C_D |V| V$ Drag Force

$F_I = \frac{\pi D^2}{4} \rho_w C_M A$ Inertia Force



Source: http://ocean.itb.ac.id, following DNV RP-F109

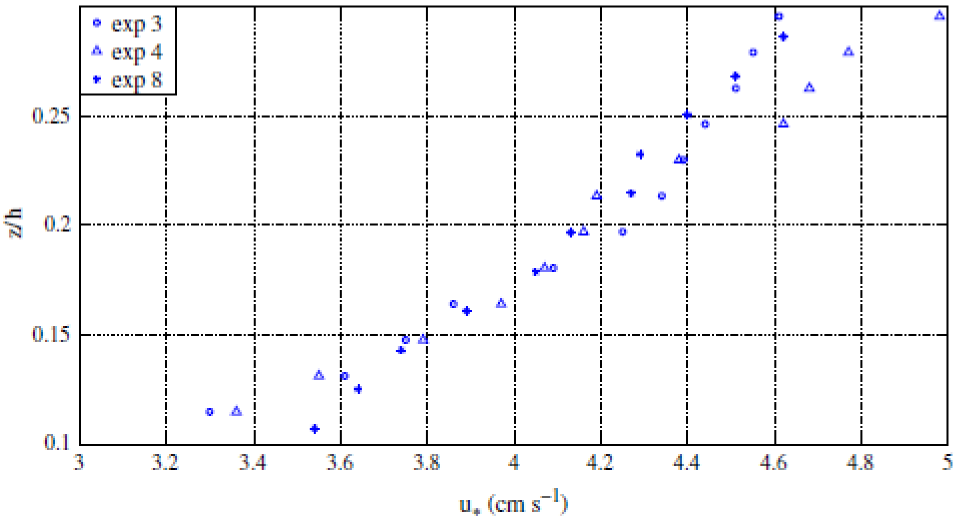
Frictional drag from the rough sea bed causes tidal flow to slow with depth. The **shear profile** for the fluid flow near the sea bed (the variation of flow speed with depth) is assumed to follow a log law (the "law of the wall"). This means that the flow speed falls logarithmically on approach to the seabed, with the shape of the profile determined by the seabed roughness using the following formula (DNV 2010):

$$V(z) = V(z_r) \cdot \frac{\ln(z + z_0) - \ln z_0}{\ln(z_r + z_0) - \ln z_0}$$

Where V(z) is the mean horizontal flow velocity in the direction of flow at a height z, $V(z_r)$ is the known flow speed at a reference height, z_r, and z_0 is the roughness length of the surface (typically between 1/10 and 1/30 of the average height of roughness elements on the surface[4]).

[4] DNV suggest z0 = 2 mm for a 25 mm pebble, and 10 mm for a 125 mm boulder.

Figure 4.2 Experimentally determined shear profile for open channel flow. X = flow velocity, Y = normalised distance from channel floor



Source: Bagherimiyab (2013)

The cable becomes unstable when the force exerted by the fluid is sufficient to overcome the resistance of the sea bed. In this case the equations in Figure 4.1 can be solved to predict the critical flow speed at which instability is expected to occur.

However this model was developed for subsea pipelines on sand or clay and not for subsea cables lying on the type of shattered rock found in the Bluemull Sound site. Cables are typically much smaller in diameter than pipelines, meaning that they lie in a lower flow zone. On a rocky seabed the cable diameter can be similar to or significantly smaller the size of seabed roughness, which means that the theoretical assumptions underlying the logarithmic shear profile do not apply. In places the cable can lie “within” the roughness layer and become shielded from the flow, inhibiting lateral motion. The application of DNV standard RP-F109 is therefore viewed as being very conservative.

4.4.1 Nova Innovation cable stability experiment

In order to empirically test cable stability at conditions typically found at a tidal site Nova Innovation conducted a series of tests in the FloWave Test Tank at Edinburgh University. A variety of cables were laid on an analogue sea floor and their stability under different flow conditions was analysed.

Figure 4.3: FloWave facility

Source: The University of Edinburgh

. Figure 4.4 shows the three seabed sections assembled together and secured to the FloWave tank floor.

Figure 4.4: Seabed analogue secured to the FloWave submersible floor, subsea cameras and flow meters in place

Source: Nova Innovation 2014 ©

Results of cable stability experiment

Empirical observations of the onset of cable instability were compared to predictions derived from DNV-RP-F109 and it was found that instability occurred at a flow rate approximately 20-40% higher than that predicted by naive application of the DNV formula. Measurements of the friction coefficient of cables to the analogue sea bed gave an indication as to why this might be the case: on a floor with roughness similar in scale to the diameter of the cable the cable has to slide upwards over a roughness feature (e.g. a boulder) in order to move laterally. This increases the effective friction coefficient of the surface, and can lead to the cable becoming "pinned" by a features on the seabed. Where a cable does experience local motion on a rough sea bed it is likely that it will move until it finds a stable location.

The implication of these results for a real tidal site is that a cable will be more stable than predicted by standard industry design methodologies.

Stability of cable in the Bluemull Sound

Our calculations show that the proposed cable will be stable in the main channel of the Bluemull Sound under peak flow conditions, using conservative assumptions and applying the conventional DNV-RP-F109 stability equations. Incorporating the results of our cable stability experiment (by increasing the seabed friction coefficient) results in an even wider margin of safety.

There are a number of factors that explain the high cable stability:

- The cable is very small diameter (48mm) and so experiences a much reduced flow rate to that at the surface (approximately 70% less flow at the cable midpoint).

- The cable includes two armour layers, and so is very dense (3000 kg/m^3 in seawater)

- The cable runs parallel with the principle direction of flow, resulting in lower drag and lift loads.

Stability in the region closer to the breakwater is difficult to reliably model, both in terms of determining the tidal flow velocity and wave loading. As set out in the Cable Plan, the stability of the cable will be closely observed after deployment. In the event that cable motion is observed in this region then concrete mattresses will be deployed to improve stability; the sea bed in the region of the breakwater changes from rock to loose sediment, and the flow rate is much lower than in the main channel, both of which are more conducive to concrete mattress stability. The location of both the cable and the mattresses will be monitored with camera and subsea surveys to confirm stability

4.5 Protection methods used for subsea cables in Scotland

SSEPD are responsible for maintaining 111 subsea cables in Scotland; all but one of these cables are unprotected for the majority of the submerged length of the cable (SSEPD 2015). Several of these cables are located in strong tidal flow regimes. SSEPD "have found no evidence that instability of these cables has been an issue for navigation or fishing". The cables are marked on Admiralty and other charts, and show up on GPS systems. According to SSEPD, "Vessel operators therefore know where the cables are and avoid them".

In their response to the 2014/15 Scottish Government Rural Affairs, Climate Change and Environment Committee inquiry into Marine Issues[5], SSEPD argue for a risk-based approach to cable protection, to ensure that protection methods employed are proportionate to the risks to the cable and to other users of the sea.

4.6 Experience of cable stability in tidal energy sites

The European Marine Energy Centre (EMEC) has ten years' experience of deploying and managing subsea cables in highly energetic marine energy sites. A review has been conducted of 12 export cables (5 at wave and 7 at tidal sites) installed at EMEC (EMEC 2015). The 7 tidal site cables have accumulated a total of approximately 250 km-years of operation with no operational failures and no issues reported with other users of the sea.

Some evidence of cable instability was observed, particularly small-scale motion ("strumming") near the shore under wave action. However no evidence of bulk cable instability under wave and tidal loading was observed. As with Nova Innovation's cable stability experiment, these findings contradicted the stability predictions of DNV-RP-F109, suggesting that this standard could be overly conservative when applied to subsea cables.

4.7 Stability of concrete mattresses in tidal flow

There is no industry standard stability design methodology, Standard or Code of Practice which suitably addresses all the diverse marine applications of concrete mattresses. Some evidence was found of research into the stability of concrete mattresses in shore-side applications (e.g. Dunlap 2001, Hughes 2006), and lab tests for a subset of mattress types intended for channel protection (Escarameia 1995). Little direct evidence was found of theoretical or empirical work on their stability in a tidal flow, other than an outline design methodology proposed by Godbold (2014). Typical practice is to apply the calculations of DNV-RP-F109 (relating to pipeline stability) to concrete mattresses[6], however this standard has not been developed for this purpose or empirically tested.

As a general principle, the forces on a concrete mattress experiencing tidal and wave loading will be the same as those outlined in Figure 4.1, with hydrodynamic lift and drag forces competing against the restoring forces of gravity and friction. Physical model testing (Godbold 2014) suggests that the main failure mode for concrete mattresses in a water flow is "edge lift". Hydrodynamic lift causes the leading corner of the mattress to be lifted sufficiently for water to flow under the mattresses. This causes mattress to roll onto itself and then continue to roll in the direction of flow. Empirical evidence suggests that mattress stability is sensitive to turbulence intensity, with critical velocities for the onset of instability reduced by more than 60% in highly turbulent environments (Escarameia 1995).

Concrete mattresses are typically applied to protect pipelines either located in regions of relatively weak tidal flow and/or to protect crossing points between pipelines. On a loosely compacted seabed the edges of the mattresses can become buried, greatly increasing the stability of the pipeline (Jas 2012). However, this effect would certainly not apply to the shattered rock seabed in the Bluemull Sound.

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[5] http://www.scottish.parliament.uk/parliamentarybusiness/CurrentCommittees/79255.aspx

[6] A previous version of this standard, DNV-RP-E305 (now deprecated) is also used; this includes simplifying assumptions making it easier to apply.

The stability of a mattress will be determined by the density of the material used and the profile of the mattress in the direction of flow. As noted in Section 2.2, a typical concrete mattress will weigh approximately ten tonnes with dimensions 5m x 3m x 300mm, with typical densities in the range 2000-2500 kg/m^3 in air (1000-1500 kg/m3 in water). A typical mattress is therefore significantly less dense (~1500 v 3000 kg/m^3) and presents a higher profile to the flow (300mm v 48mm) than the cable it is intended to protect. In addition, due to the shear profile, the mattress experiences a significantly higher average flow rate than the cable (~30% higher flow speed at the Bluemull Sound).

Whilst the shape of the mattress might be expected to offer some additional stability, the existing of the "edge lift" failure mode provides a mechanism where instability at the edge of the mattress can quickly propagate to catastrophic failure of the whole mattress. We are aware of one case where this has occurred in a UK tidal energy project; a mattress intended to protect a short length of cable did not stay in place for a single tidal cycle and was eventually recovered.

4.8 Summary of review findings

The review of MAIB reports identified no cases of cable snagging by fishing vessels. Such events do occasionally occur, but the outcome is not typically sufficiently severe as to merit an MAIB investigation.

A single report of cable snagging by an anchor of a large vessel was identified (Nordsee 2007), where the cable involved had initially been buried. It is not clear whether the cable had become exposed due to motion of the seabed or whether the anchor penetrated the seabed to expose the cable.

One fatality was identified that occurred during deployment of concrete mattresses for an offshore windfarm (Riffgat 2013).

No serious incidents were identified involving fishing vessels or anchors snagging on concrete mattresses. However, evidence was provided that concrete mattresses present "a significant snagging hazard" to fishing vessels.

Results from Nova Innovation's cable stability experiment and a cable stability observational study undertaken at EMEC suggest that the standard typically used to assess stability of subsea cables is likely to be conservative. Even with this caveat noted, application of this standard implies that the cables proposed for the project will be stable in the main channel of the Bluemull Sound.

SSEPD own, operate and maintain 111 subsea cables in Scottish waters, many of which have been in place for over 60 years. All but one of these cables are unprotected for the majority of their length. No evidence has been found of any serious incident involving snagging of anchors or fishing gear on any of these cables

No research was found regarding the stability of concrete mattresses in strong tidal regimes. There are no design standards for stability of concrete mattresses, and no empirical evidence was found relating to the stability of mattresses on a rocky sea bed in a strong tidal regime. Anecdotal evidence suggests that concrete mattresses are not stable in strong tidal flow regimes. The analysis undertaken suggests that concrete mattresses deployed in the main channel of the Bluemull Sound would be less stable than the cable they are intended to protect.

5 Vessel activity

A Navigational Risk Assessment (NRA) has been conducted for this project, and shared with statutory consultees and Marine Scotland (Nova Innovation 2015). The NRA included consultation with local fishing and recreational vessel bodies and a survey of marine traffic. Findings from the NRA relevant to this Cable Risk Assessment are summarised below.

5.1 Consultations

The following bodies were consulted with in the preparation of the Navigational Risk Assessment:

- Shetland Ports and Harbours
- Lerwick Boating Club
- Shetland Shellfish Management Organisation (SSMO)
- Shetland Fishermen's Association (SFA)

5.2 Traffic Survey

A traffic survey was conducted drawing on the following information sources:

1. An Automatic Identification System (AIS) receiver located on Cullivoe Pier.
2. Fishing activity data from the NAFC Marine Centre (NAFC).
3. Consultation with the Shetland Fishermen's Association and the Shetland Shellfish Management Organisation.

5.2.1 Shetland Isles Overview

Shipping passes around the islands and a number of ferry routes and regular dry cargo trades run from the mainland and between the individual Islands in the Shetlands. The oil terminal at Sullom Voe generates calls by tankers well in excess of 350 metre in length together with oil rig and other support services. Construction work at Sullom Voe and at surrounding oil fields and development projects also generate vessel traffic. Shallow water and restricted navigation means that larger vessels avoid the Bluemull Sound.

5.2.2 Cullivoe Pier

The Harbour at Cullivoe has an ice house used by the fishing industry. It is primarily used by fishing and service vessels although there is also some leisure traffic.

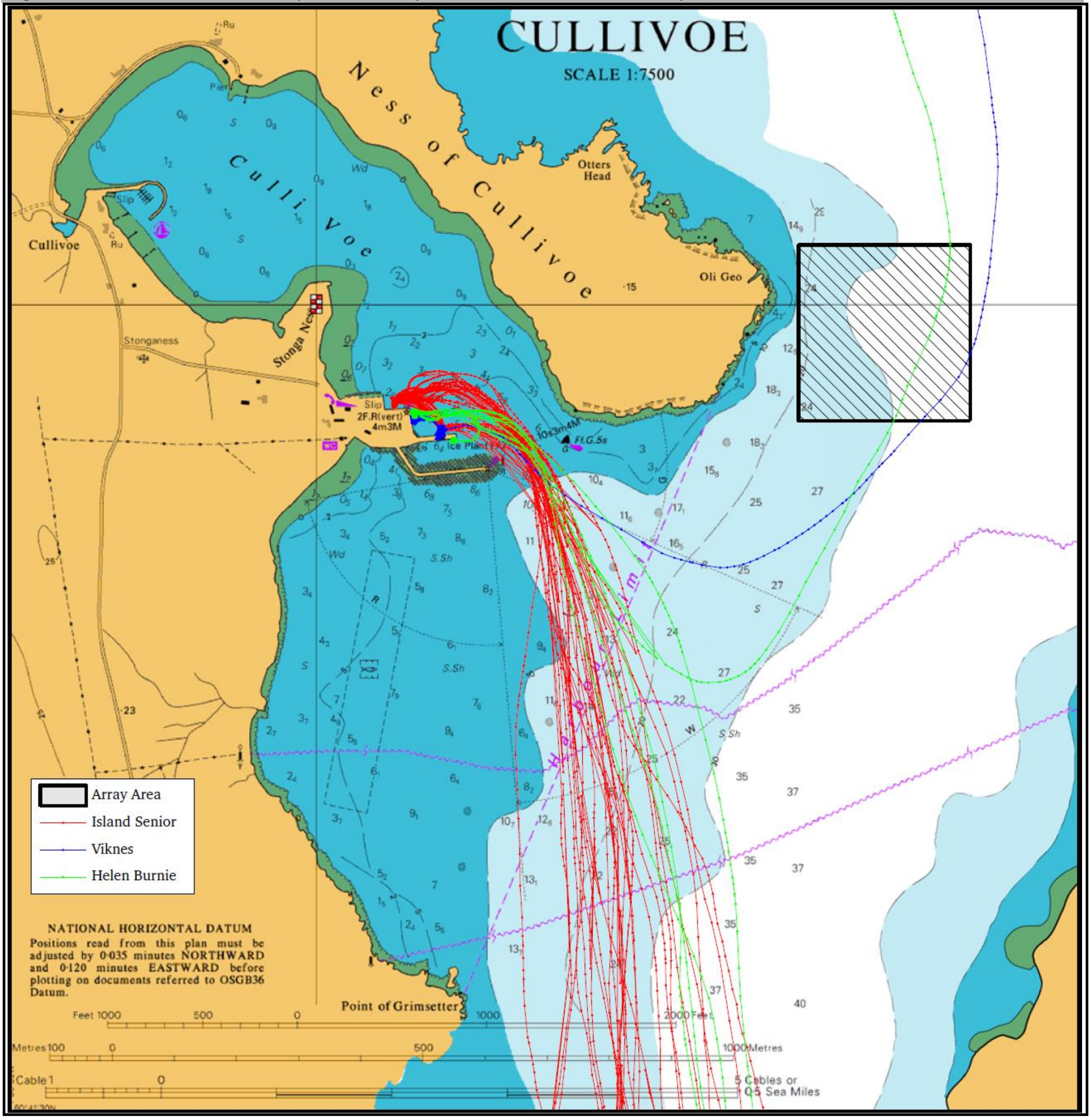
5.2.3 Ferry services

To the South of the Bluemull Sound, approximately 2 km from the array site, ferries run between Gutcher, Belmont and Hamars Ness. The ferry occasionally berths at Cullivoe Pier in poor weather or to refuel.

5.2.4 AIS traffic survey

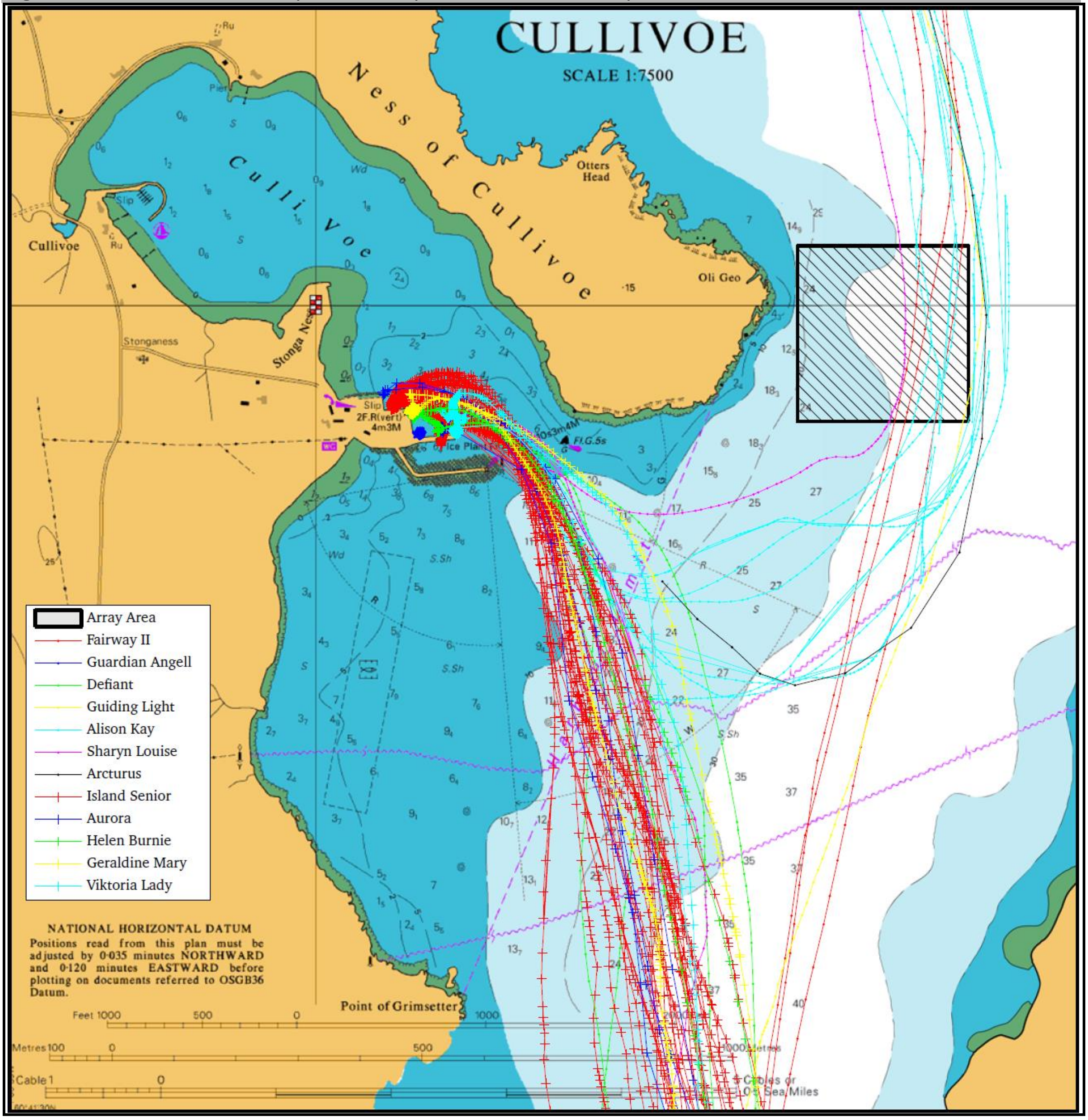
AIS data was collected over two 2-week periods, one in summer (2nd to 15th of July 2014) and one in winter (1st to 14th of February 2015). The results are shown in Figure 5.1 and Figure 5.2.

Figure 5.1 Results of AIS survey of the array site conducted in February 2015



Source: Nova Innovation 2015 ©, UKHO

Figure 5.2 Results of AIS survey of the array site conducted in July 2014



Source: Nova Innovation 2015 ©, UKHO

5.2.5 Non AIS Traffic

Much of the traffic using the Bluemull Sound consists of smaller vessels which will not necessarily be fitted with AIS (mandatory for ships over 300 gross tonnes). This will include fishing vessels, service boats and leisure boats. Many of these vessels use Bluemull Sound as a transit route. The local harbour at Cullivoe also attracts vessels to the area and includes a small marina for leisure boats.

To better understand the local traffic and site specific issues, the position and size of the deployment area was discussed and agreed in consultation with Ports and Harbours, the Shetland Fishermen's Association, SSMO and the Lerwick Boating Club. The position of the devices and cables was selected to avoid any area used for safe anchorage and to minimise any risk to shipping in the area.

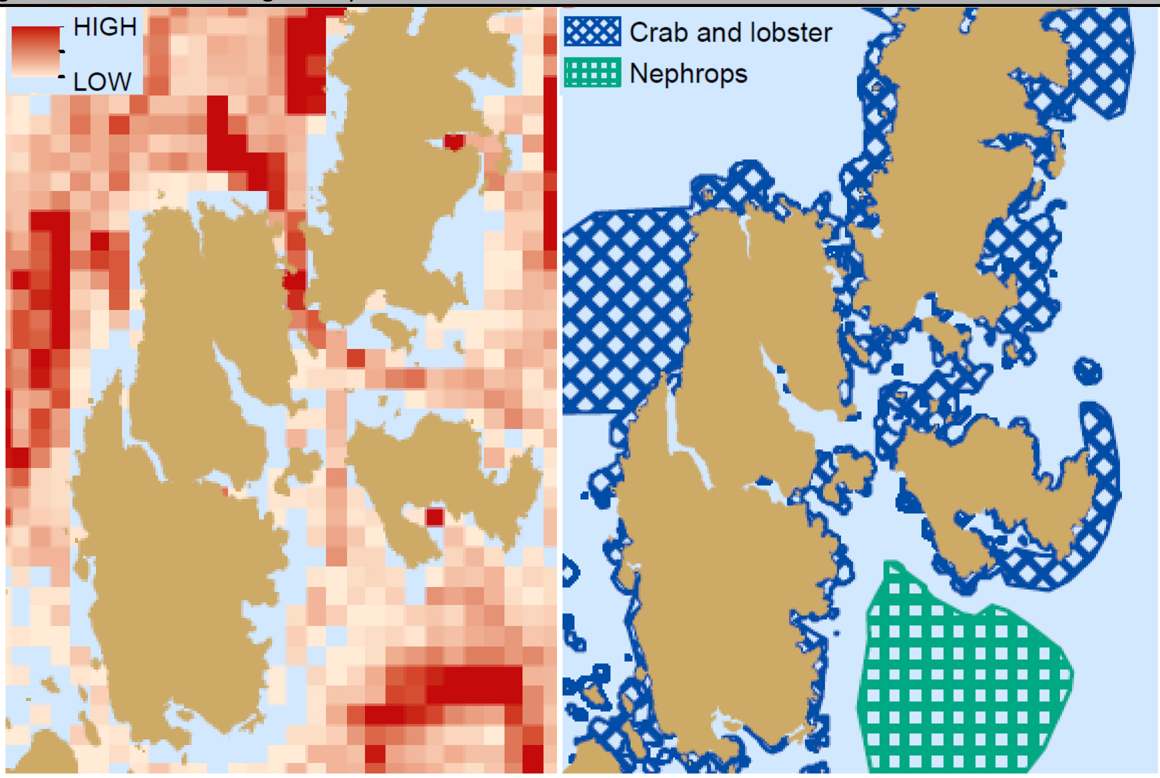
5.2.6 Fishing activity

Data on fishing grounds around the Shetland coast was sourced from the NAFC. Two charts from the Shetland Marine Spatial Plan are provided in Figure 5.3, showing (a) indicative demersal fishing activity derived from

VMS data, and (b) shellfish creeling grounds, based on NAFC modelling and consultations with shellfish fishermen.

Regarding the demersal fishing activity data, NAFC caution that "VMS data for larger vessels tends to overestimate fishing effort in this area as the strong tidal flow means that boats travel more slowly, and this gives the false appearance of fishing effort". This is because "fishing effort" is derived from VMS data by assuming that slow vessel speeds are associated with fishing activity; vessels arriving at Cullivoe Pier will also be incorrectly flagged as "fishing" using this data source. Consultation with the SFA and Shetland Shellfish Management Organisation indicates that, whilst creeling does take place around in the Bluemull Sound, the selected site is not an active fishing or creeling area. The rocky substrate in the Sound means that the area is not suitable for dredging or trawling.

Figure 5.3 Indicative fishing activity in and around the Bluemull Sound



(a) Indicative demersal fishing effort (b) Shellfish creeling grounds

Source: NAFC 2013

5.2.7 Anchorage

The cable route was selected to avoid any areas used for anchorage; a fact confirmed by consultation with local stakeholders. The selected cable route runs to the South of the breakwater protecting the harbour, in an area exposed to tides and waves. Vessels do not anchor in this area given the availability of a safe harbour on the other side of the breakwater.

5.2.8 Traffic Survey Conclusion

Large vessel traffic intensity around the site is low. The site and cable route have been selected in consultation with local stakeholders and avoids any area used for anchorage or fishing. The selected layout has been deemed acceptable by the relevant parties consulted during the NRA.

6 Cable protection options

A number of different cable protection/stabilisation solutions were considered for this project; these are described in more detail below.

- Integral protection
- Concrete mattresses
- Trenching/burial
- Rock dumping
- Grout or rock bags
- Anchors or rock bolts

6.1 Integral protection

6.1.1 Cable Armouring

Cable armour involves a sheath of galvanised steel wire, integral to the cable, wrapped helically around the conducting cores (Figure 6.1). A number of options including single, double, triple and variable layer galvanised armoured cables were investigated. Double armour was selected as it offers good torque balance, good protection against abrasion along with relative ease of termination and deployment. The other options are deemed less suitable:

1) Single armour is more prone to damage over a 20 year life and provides less protection from abrasion than double armour.

2) Triple armour is prone to losing internal torque balance over time, is difficult to handle (stiff and heavy), and is more expensive to manufacture.

3) Variable armour layering (e.g. single layer in exposed area, double layer for the remainder) is often used in dynamic situations such as ROV or FPSO umbilical's, however it must be designed to length for the specific application. This means expensive bespoke manufacture rather than an off-reel 'cut and terminate' to length solution.

Figure 6.1: General sub-sea cable architecture

Source: www.nexans.co.uk

6.1.2 Outer Jacket and Additional Integral Protection

All cable manufacturers approached for this project agree that a High Density Polyethylene (HDPE) outer jacket or sheath is the most effective means by which to protect against abrasion and impact, both during installation and over the cable lifetime. Although a polypropylene wrap is often utilised in subsea cables our suppliers noted that this is more often for laying purposes from a carousel where sufficient grip/friction is required on the cable to utilise the necessary cable tensioners and motors (a carousel will not be required to lay cables in this array). Cable abrasion experiments conducted by Nova Innovation prove that HDPE is a very hard-wearing surface and sufficient to protect a cable against likely abrasion due to hydrodynamic loading in the Bluemull Sound for the 20 year design lifetime.

6.2 Concrete mattresses

Concrete mattresses are made up of flexible segments of concrete, typically held together by polypropylene ropes. They provide both cable protection and stabilisation and are available in a range of standard sizes or can be designed to meet specific requirements. A typical standard size is 6m x 3m x 0.15m with a submerged weight of roughly 2 tonnes. To deploy they are lowered over the cable using a lifting frame, then released automatically. Divers are typically used for accurate placement.

Figure 6.2: Concrete mattresses

Source: Tekmar

Two hours deployment time is typically required per mattress (largely preparation time), making the deployment cost per metre very high. Mattresses are typically used to provide protection and stability in targeted areas. Costs range from £400 per mattress upwards (excluding delivery), with additional costs for a lifting frame and divers for deployment. Deployment of such mattresses in fierce tidal streams has very seldom been practiced and would incur very significant deployment vessel and operational risks.

Cost of concrete mattress protection for the Shetland Tidal Array

Each cable in the array is approximately 1km in length, requiring approximately 160 mattresses for full coverage: at £400 per mattress this would cost £64,000 per cable – approximately twice the cost of the cable. This cost does not include station keeping in tidal streams or the invariably high down-time between high-flow periods when it would not be safe or practicable to be working on site.

Due to high drag forces the mattresses cannot be laid in strong tides, with a maximum safe flow speed of approximately 0.5 m/s for safe operations, corresponding to approximately a 40 minute window in the Bluemull Sound during neap tides. Assumptions: a frame is constructed that can deploy 3 mats at a time using hydraulic shackles; sufficient accuracy can be achieved without the use of divers (but ROV required); 3 mats laid per slack tide; 12 mats per day (24 hour working); 25% contingency for weather delays (typical of summer conditions in Shetland); 20% uplift to allow for misplaced/replaced mats; capability to deploy in protected shallow waters at spring tides. Under these assumptions it would take approximately 20 days to cover a single cable. With vessel costs at tens of thousands of pounds per day (DP2 vessel; 24 hour working; including consumables; including ROV; excluding divers) and including mobilisation costs, deployment of concrete mattresses along the length of one cable would cost at least ten times as much as the cable. Note that the narrow deployment window available over slack tide significantly increases the cost of this solution at a tidal site.

In total, the cost of protecting a 1 km cable with concrete mattresses in the Bluemull Sound would be at least 12 times the cost of the double-armoured cable, and would increase the capital cost of the project by over 30%.

6.3 Trenching/burial

This technique is widely used to protect subsea cables, and is the preferred solution for cables in offshore wind farms. A trenching plough or rock-cutter is used to dig a trench in the sea bed in which the cable is deposited.

The trench can be back-filled by the plough or left to be covered over time by the motion of sediment on the seabed.

This technique is appropriate for sites consisting of sand or clay. However, it is not suitable for tidal sites like the Bluemull Sound which largely consists of hard rock.

Figure 6.3: Cable trenching plough

Source: www.4coffshore.com

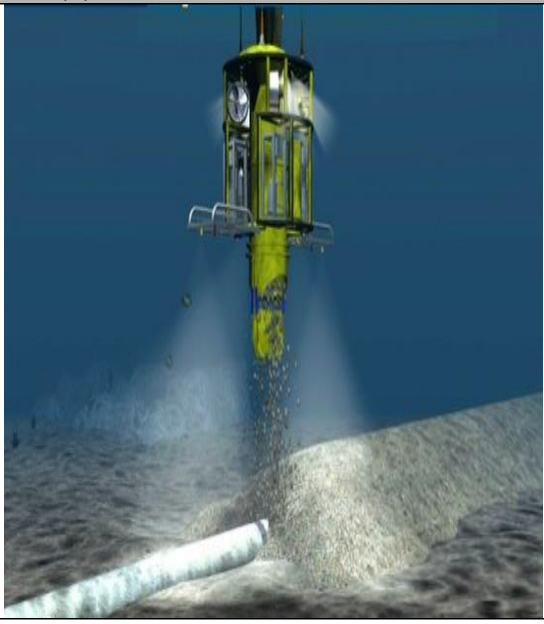
6.4 Rock dumping

This involves laying a graded rock "berm" onto a cable, with rocks deposited from the side of a vessel or through a fall pipe. This technique is commonly used in the oil and gas, offshore wind and telecom industries to protect pipes and cables.

Consultation with suppliers suggests that, whilst not commonly used in highly energetic tidal areas, this technique could theoretically be deployed using a suitable grade and density of rock and deployment strategy. A flexible fall pipe DP vessel would typically be used for >30m water depth, with large (300mm+) rocks deposited over a "cushion" layer of smaller grade rock to protect the cable. Maximum current speed for fall pipe operations is approximately 3 knots; operations would typically be conducted during slack, neap tides. Berm design (stone type and size, number of layers, berm profile) needs to be carefully designed taking into account the site, hydrodynamic loads, and the risks protected against.

However, the fact that the Bluemull Sound is largely swept clean of boulders makes clear that berm stability would be an issue, risking cable integrity and ongoing significant annual maintenance costs. Rock dumping remains a snagging risk for fishermen and anchors.

Figure 6.4: Rock dumping via a fall pipe



Source: www.theartofdredging.com

6.5 Grout or rock bags

Grout or rock bags are available in an assortment of standard and bespoke shapes, sizes, densities and filling material. Weights range from 25 kg to 1.5 tonnes. To deploy, they are lowered over the cable and released either remotely or by a diver/ROV. Grout bags cure after installation to increase stabilisation. Larger bags are also available as 'drop bags' with an underside release mechanism which can be operated by a diver or ROV to release the loose rocks over the cable protection area. Typical capital costs for grout and rock bags range from £200/tonne upwards (excluding delivery), with lifting gear and an ROV or diver potentially required for deployment.

This type of protection could potentially be used to protect the cable; however, as with the analysis for concrete mattresses in Section 4.7, the bag would need to be carefully designed to ensure this solution would provide any more hydrodynamic stability than a bare cable). In addition, as with concrete mattresses (a) it is not this stabilisation method would not have any positive impact on navigational safety and (b) it would be extremely expensive to use this solution to protect the entire length of cable.

Figure 6.5: Small grout bag

Source: Pipeshield International Ltd.

Figure 6.6: Offshore bulk bags

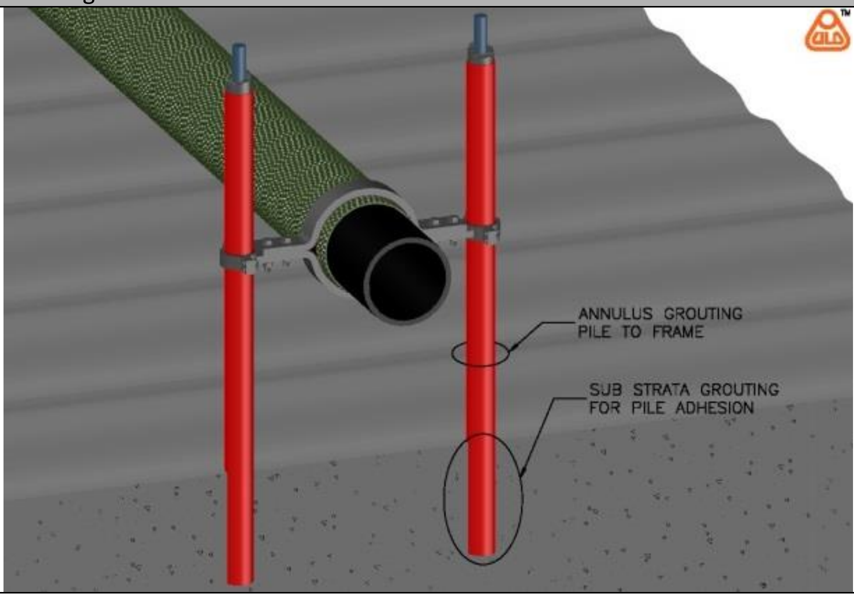
Source: www.sps.gb.com

6.6 Anchors or rock bolts

Anchors or rock bolts can be used to stabilise cables where the seabed can maintain lateral loads. Bolts are used to stabilise subsea pipelines in rocky areas where trenching is not an option. They are typically installed using divers: bolts are drilled into the ground and grouted; anchors can be pushed or screwed into softer ground. The need for diver support typically makes this an expensive option.

This solution could potentially be used to increase the stability of the cable. However, it offers limited benefits with regard to navigational safety. The likely outcome is an even more 'fixed' point producing a snagging risk which would be even more likely to cause a capsize.

Figure 6.7: Rock bolting



Source: www.ulosystems.com

7 Summary risk assessment of cable protection options

A risk assessment of cable protection options was undertaken, and is included in Section 8. Table 7.1 summarises the outcomes for the different cable protection options considered. The assessment considers three types of risk: risks involved with deployment; risks involved with the operation of the array; navigational risks to other users of the sea. Environmental impact and cost were also considered. Environmental impact is informed by the study Review Of Cabling Techniques And Environmental Effects Applicable To The Offshore Wind Farm Industry (BERR 2008).

Table 7.1 Summary of cable protection option risk assessment – risks for 'as deployed' scenarios

Option	Deployment risk	Operational Risk	Navigational risk	Environmental impact	Lifetime Cost
Integral armour	Low	Low	Low	Low	Medium
Concrete mattresses*	High	High	Medium	Medium	High
Rock dumping	Medium	Medium	Medium	Medium	High
Anchors or rock bolts	High	High	Medium	Medium	Medium
Trenching/burial	Not feasible	Not feasible	Not feasible	Not feasible	Not feasible

*Source: Copyright © Nova Innovation 2015 *The same risk assessment applies for grout/rock bags*

The results indicate that a double-armoured cable is the lowest risk solution for the Bluemull Sound site, considering both the risk to personnel and vessels involved in deployment and operations, and risks to other users of the sea.

There are a number of uncertainties involved in this assessment: in particular those related to the stability of the different protection measures in strong tidal streams, and the relative snagging risks presented by the different options. We propose to deal with these uncertainties relating to the preferred solution by monitoring the cable for instability and recorded incidents of snagging and employing additional protective measures if required (for example, deployment of concrete mattresses in regions of low tidal flow if required for stability).

8 Cable protection options comparative risk assessment

This section contains a comparative, high-level risk assessment of the different cable protection options considered.

Table 8.1 Cable protection options comparative risk assessment

Option	Deployment risk	Operational risk	Navigational risk	Environmental impact	Lifetime cost
Integral armour	Low - each cable can be spooled in a single durig one slack tide operation from a vessel without diver support.	Low - cable operations might occasionally involve lifting and re-deploying the cable. Cable can be lifted in a single operation without diver support.	Low - cable is located outside anchorage and fishing areas so risk of snagging is low.	Low - seabed footprint is small; electromagnetic fields are much smaller than for most offshore cables due to low power and shielding from double armour.	Medium - increased cost for double armour layer cf single armour; higher deployment cost due to increased weight and stiffness. Intervention costs minimised due to ease of recovery and deployment. Frequency of intervention higher than for buried cable due to abrasion.
Concrete mattresses **(also grout/rock bags)**	High - covering a complete cable would take 3 weeks of offshore operations. Risks of injury to offshore workers from lifting operations, and collision risk to passing vessels.	High - mattresses would need to be lifted to recover the cable, necessitating long periods of offshore working with all the associated risks. Connector repair would need to be conducted on-site, with vessel holding station in a strong tidal stream. Mattress could protect cable from snagging damage, but could also lead to damage from pinch points.	Medium - mattresses present a snagging risk. Potential instability of mattresses could lead to them becoming scattered around the sound, increasing navigation risks. Increased period of offshore working for installation and maintenance vessels increases collision risk.	Medium - ~60 times larger impact (seabed area) than for the cable. Deployment and recovery would be likely to destroy sessile species located beneath the mattresses.	High - capital cost for mattresses; vessel costs for deployment and operations. Mattress placement could damage cable on hard substrate requiring expensive repair. Likely that mattresses would need to be surveyed and maintained annually and after storms.
Rock dumping	Medium - involves increased amount of offshore working, increasing risk of collision with marine traffic.	Medium - rock would need to be cleared to recover the cable, necessitating increased periods of offshore working. Connector repair would need to be conducted on-site, with vessel holding station in a strong tidal stream. Rock berm could protect cable from snagging damage, but could also lead to damage from pinch points.	Medium - rock berm presents a snagging risk. Potential instability of rocks could lead to them becoming scattered around the sound, increasing navigation risks. Increased period of offshore working for installation and maintenance vessels increases collision risk.	Medium - ~40 times larger impact (seabed area) than for the cable alone. Deployment and recovery would be likely to destroy sessile species located beneath the berm.	High - material and vessel costs. Rock placement could damage cables. Cable repair extremely expensive. Berm maintenance required annually and after storms.
Anchors or rock bolts	High - requires diver deployment in the tidal zone up to 40m depth. Increased time for vessels on-site increases collision risk.	High - would need divers to remove and replace bolts for cable recovery and replacement.	Medium - increased stability from pinning, but would significantly increase forces experienced by snagged anchors or gear.	Medium - noise and sediment from offshore drilling.	Medium - low additional material cost, but diver deployment in tidal sites expensive.
Trenching/burial	Not practical at this site	Not practical at this site	Not practical at this site	Not practical at this site	Not practical at this site

Source: Copyright © Nova Innovation 2015

9 Hazard log – summary of safety issues and mitigation measures for double armoured cable

This section summarises the navigational hazards during installation, operation and decommissioning of the proposed cable protection option: a double-armoured cable in an HDPE sheath.

Element	Phase	Hazard	Consequence	Initial Risk			Control / Mitigation	Residual Risk		
				Frequency	Consequence	Risk		Frequency	Consequence	Risk
Cable	Installation or Decommissioning (same hazards)	Vessel Not Under Command (NUC)	Collision between NUC vessel and installation vessel(s) leading to vessel damage/injury/loss of life	Remote	Major	Tolerable with additional controls	Notice to Mariners/ Navigation Warnings/ Vessel Lighting and Markings Compliance with COLREGs	Extremely Remote	Major	Tolerable with Monitoring
		Vessel enters array area and collides with installation vessel	Collision between vessels leading to damage to vessel/ injury/ loss of life	Remote	Major	Tolerable with additional controls	Notice to Mariners/ Navigation Warnings/ Vessel Lighting and Markings/ Compliance with COLREGs	Extremely Remote	Major	Tolerable with Monitoring
		Use of incorrect IMM VHF channel	Interference with IMM VHF ship/shore and ship/ship communications	Reasonably probable	Minor	Tolerable with additional controls	Installation vessel(s) to agree working channel with Ports and Harbours	Extremely Remote	Minor	Broadly Acceptable

Element	Phase	Hazard	Consequence	Initial Risk			Control / Mitigation	Residual Risk		
				Frequency	Consequence	Risk		Frequency	Consequence	Risk
Cable	Operation & maintenance	Vessel Not Under Command (NUC)	Collision between NUC vessel and device or maintenance vessel leading to vessel or device damage/injury/loss of life	Extremely Remote	Major	Tolerable with monitoring	Notice to Mariners/ Navigation Warnings/ Vessel Lighting and Markings/ Device on-board monitoring for impacts/ CCTV	Extremely Remote	Major	Tolerable with Monitoring
		Vessel enters array area and collides with maintenance/ inspection vessel	Collision between vessels leading to damage to vessel/ injury/ loss of life	Remote	Major	Tolerable with additional controls	Notice to Mariners/ Navigation Warnings/ Vessel Lighting and Markings/ Compliance with COLREGs	Extremely Remote	Major	Tolerable with Monitoring
		Cable Snagged by object, e.g. anchor, tackle	Cable damaged or vessel unable to free anchor. Damage to vessel or cable. In extreme can lead to loss of vessel.	Remote	Major	Tolerable with additional controls	Update Admiralty charts with cable route. Provide contact point for Shetland OREC to liaise with snagged vessels.	Remote	Minor	Tolerable with Monitoring
		Movement of cable in tidal stream leads to cable snagging by object e.g. anchor, tackle	Cable damaged or vessel unable to free anchor. Damage to vessel or cable. In extreme can lead to loss of vessel.	Remote	Major	Tolerable with additional controls	Survey cable position and provide additional stability in areas where movement is observed. Update Admiralty charts with any changes in cable position.	Extremely Remote	Major	Tolerable with monitoring

9.1 Risk Criticality Matrix used in the Risk Log

Risk Criticality	Condition	Explanation
Broadly Acceptable	None	Technical review is required to confirm the risk assessment is reasonable. No further action is required
Broadly Acceptable	None	Technical review is required to confirm the risk assessment is reasonable. No further action is required
Tolerable with monitoring	With a commitment to risk monitoring and reduction during operation	Risk must be mitigated with engineering and/or administrative controls. Must verify that procedures and controls cited are in place and periodically checked
Tolerable with Additional Controls	With a commitment to further risk reduction before operation	Risk should be mitigated with design modification, engineering and/or administrative control to a Risk Class of 4 or below before construction
Tolerable with Modifications	With a commitment to further risk reduction before construction	Risk must be mitigated with design modification and/or engineering control to a Risk Class of 5 or lower before consent
Unacceptable	None	Risk must be mitigated with design modification and/or engineering control to a Risk Class of 5 or lower before consent
Unacceptable	None	Risk must be mitigated with design modification and/or engineering control to a Risk Class of 5 or lower before consent

9.2 Risk Tolerability Matrix used in the Risk Log

Hazard Identification Risk Assessment (HIRA)					
HIRA Risk Matrix					
	Consequence	Insignificant	Minor	Major	Catastrophic
Frequency	Definition	No significant harm to people	Injury to vessel crew Injury to OREI installation crew Injury on the shore	Loss of vessel crew members (1-3) Loss of OREI installation or maintenance crew members (1-3) Fatalities on shore (1-3)	Total loss of vessel crew Total loss of OREI installation or maintenance crew Multiple fatalities onshore
Frequent	Likely to happen annually or more frequently	Tolerable with Additional Controls	Tolerable with Modifications	Unacceptable	Unacceptable
Reasonably Probable	Likely to happen duting the license period of an OREI (nominally 20 years)	Tolerable with monitoring	Tolerable with Additional Controls	Tolerable with Modifications	Unacceptable
Remote	Unlikely (but not exceptional) to happen during the licence period	Broadly Acceptable	Tolerable with monitoring	Tolerable with Additional Controls	Tolerable with Modifications
Extremely Remote	Only likely to happen in exceptional circumstances	Broadly Acceptable	Broadly Acceptable	Tolerable with monitoring	Tolerable with Additional Controls

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