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ALCATEL SUBMARINE NETWORK

Havhingsten - Ireland

Appendix C - Cable Burial Assessment

P2228_R4693_Rev 4 App C | November 2019

Intertek Energy & Water Consultancy Services
Exchange House, Station Road, Liphook, Hampshire GU30 7DW, United Kingdom

HAVHINGSTEN FIBRE OPTIC CABLE SYSTEM

SEGMENT 1-1

BU PORT ERIN TO BMH LOUGHSHINNY

BURIAL ASSESSMENT STUDY

Rev	Date	Description	Prepared by
Rev 1	Jan 2019	Issued for internal review	GH
Rev 2	May 2019	Final Issue	GH

CONTENTS

TABLES

FIGURES

1 INTRODUCTION

Revision 02 of this report reflects the PSR03 Route Position List (RPL) and survey data supplied to Alcatel Submarine Networks by Fugro Germany Marine GmbH.

This burial feasibility study is for the proposed Havhingsten Fibre Optic Cable Project Segment 1-1 which runs from BU Port Erin to BMH Loughshinny (Ireland). See Figure 1-1 for an overview. The PSR03 RPL cable route is 80.626km long. Burial is planned throughout the segment, where seabed conditions allow.

Target Burial Cover Depth	Nominal CPT Spacing	Nominal Core Spacing
1.5m	10km	10km

Table 1-1: Target Burial Depth & Nominal CPT/Gravity Core Spacing

Appendix 1 provides the burial assessment statements. The predictions are based on the data supplied from the marine geophysical and geotechnical survey. Data used in the compilation of this report included CPT and core data, bathymetry data, sidescan sonar data and sub-bottom profiler data.

Appendix 1 gives the BAS Summary and a summary of sediment sample and CPT data is shown in Appendix 2

The main method of installation is assumed to be a SMD HD 1.5m-share seabed plough, weighing 37 Tonnes in air, deployed from an Ile de Class installation vessel. The direction of installation is assumed to be from the BU Port Erin location to the BMH at Loughshinny, Ireland.

Figure 1-1: Location Map for the Havhingsten Segment S1-1

1.1 Route Summary & Recommendations

- 100% of the route is expected to be subject to a burial operation:
  - *95.21% of the route is ploughable*
  - *4.79% will be surface laid then subject to PLB. This includes pipeline crossings, BU integration and shore end.*

Burial conditions along the entire route are generally expected to be very good. Seabed sediment and to the target burial depth are predominantly very soft to soft clay with some denser sandy surficial deposits near the start of the route at the BU.

Some of the CPT and Gravity Core samples have shown that the shear strength is often very low and sometimes below 5kPa which is regarding as the minimum strength required to support the plough. In these cases, there may be the tendency for some overburial to occur.

From approximately KP 25 to KP 70 numerous trawl scars are observed which may pose a threat to the cable if there is reduced burial. Research work has identified the expected maximum penetration depth for trawl boards is 300mm and the cable will be buried beneath this external threat.

At KP 45.610 the proposed route passes approximately 100m to the southeast of a wreck identified with dimensions of 24.2m length x 8.9m width and 4.2m height.

Where areas of boulders have been encountered routing has been designed to avoid them, however, there does remain the possibility of additional buried boulders which may cause localised high tensions.

Sub-bottom profile data indicates a thick layer of sediments all the way to the mouth of Loughshinny harbour.

The seabed only shows very gentle to gentle gradients and no problems are expected with steep slopes causing plough instability.

1.2 Target Burial Depth, the Burial Protection Index & Predicted Burial Depths

The Burial Protection Index (BPI) concept tells us that a cable will be as adequately protected against most external threats in stiffer/denser sediment with a shallower burial depth, as it would be in softer/looser sediment to a greater depth.

The BPI concept is based on a value of 1 providing adequate protection against the majority of bottom fishing (trawling) and the most common fishing gear in a soft/firm clay of 40kPa shear strength. Allan (1998) recommends that a BPI of 2 to 3 would be required to protect against ships' anchors, depending on size.

Figure 1-2 below shows the Burial Protection Index concept for various sediment types. For example, in denser sands, a burial depth of 0.75m would provide the same protection as >2m burial in very soft clay.

Figure 1-3 builds on the initial BPI concept, providing the burial depth required to achieve a BPI of 1 in various clay shear strengths. Similarly, Figure 1-5 provides the depths required in various relative densities for sands. Table 1-2 summarises the burial depths that would provide a BPI of 1 in various sediment types and strengths and provides a recommendation for the mid-range of each sediment classification.

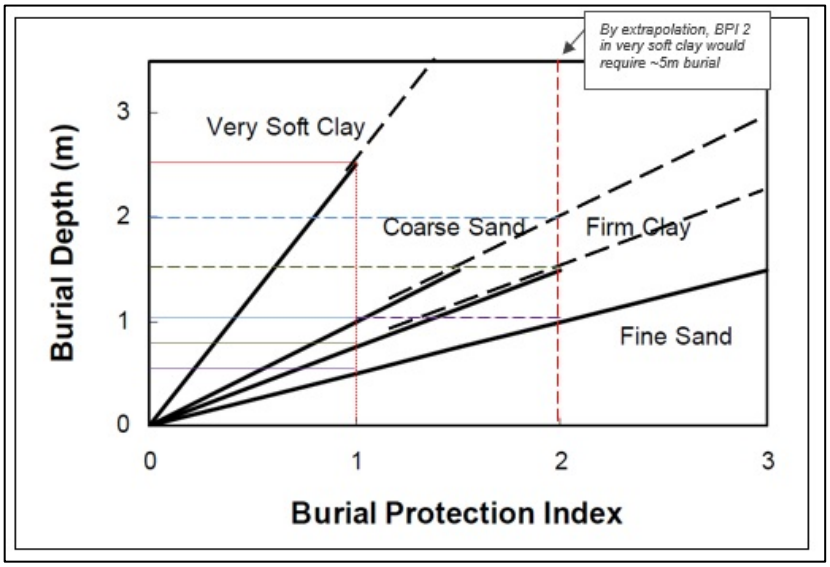

Figure 1-2: Burial Protection Index in Various Sediments (modified, after Mole et al, 1997)

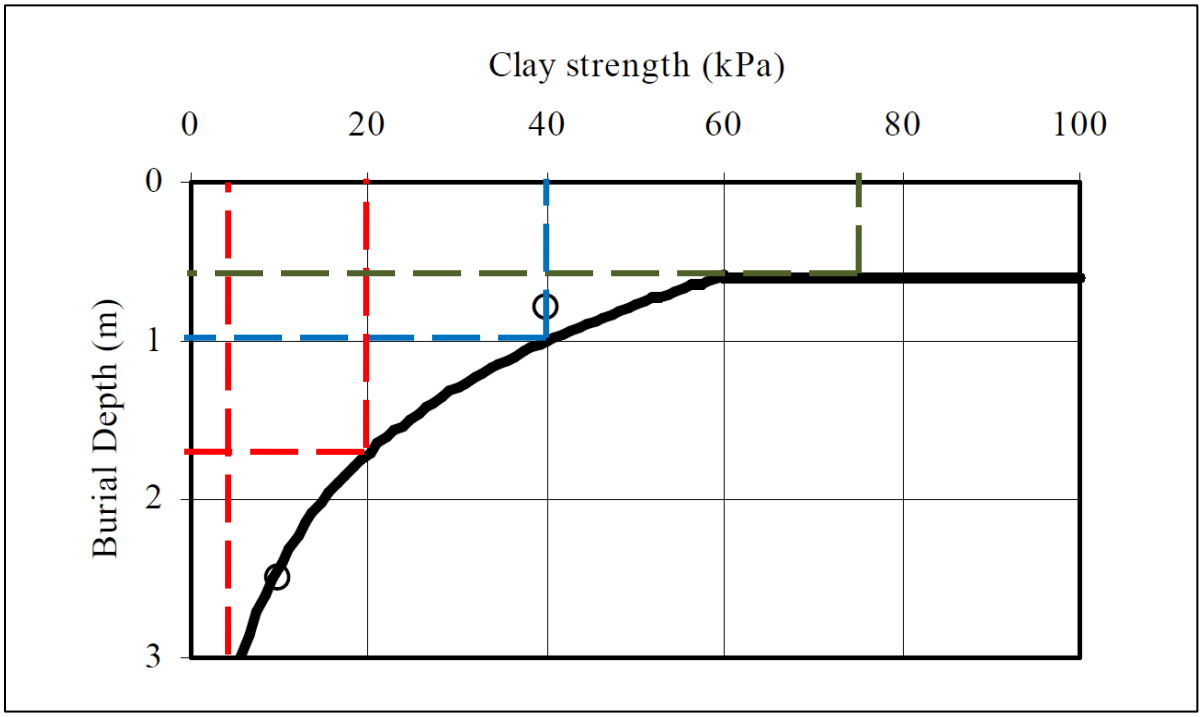

Figure 1-3: Recommended Burial Depth for BPI=1 with Varying Shear Strength in Clays (modified, from Allan & Comrie, 2001). O=Values recommended by Mole (1997)

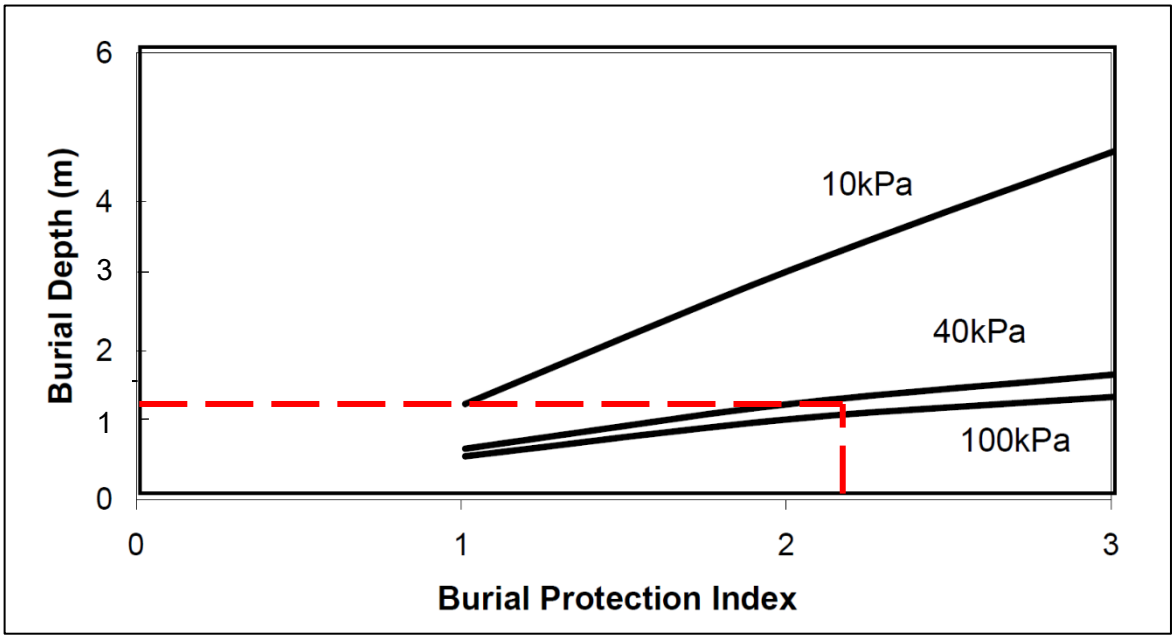

Figure 1-4: Burial Depth vs. BPI in Various Clay Shear Strengths (from Allan, 1998)

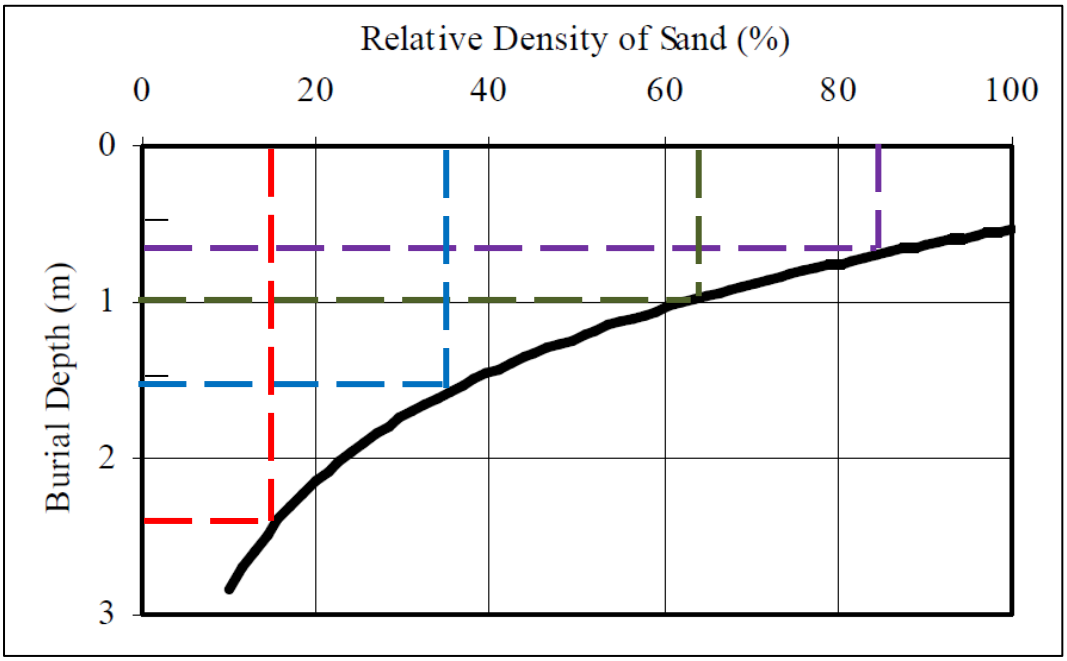

Figure 1-5: Recommended Depth to Achieve BPI=1 with Varying Relative Density in Sand (after Allan & Comrie, 2001)

Sediment Type	Relative Density (Sand)/ Shear Strength (Clay) Ranges	Burial Depth Range for Lower & Upper Bounds of Strength Range	
CLAYS	Extremely low to very low	0-20kPa	>3.0m to 1.75m
	Low (II)	20-40kPa	1.75m to 1.0m
	Medium (III)	40-75kPa	1.0m to 0.6m
	High to Extremely High (IV-	>75kPa	0.6m
SANDS	Very Loose (I)	<15% RD	>2.5m
	Loose (II)	15-35% RD	2.5m to 1.6m
	Medium Dense (III)	35-65% RD	1.6m to 1.0m
	Dense (IV)	65-85% RD	1.0m to 0.75m
	Very Dense (V)	>85% RD	0.75m to <0.5m

Table 1-2: Recommended Burial Depths to Achieve BPI=1 in Various Seabeds

References:

Allan P.G., and Comrie R.J. (2001) The Selection of Appropriate Burial Tools and Burial Depths. SubOptic 2001 Kyoto

Allan, P.G. (1998) Selecting Appropriate Cable Burial Depths—A Methodology. IBC Conference on Submarine Communications. The Future of Network Infrastructure, Cannes, November 1998.

Mole, P., Featherstone, J. and Winter, S. (1997) Cable Protection – Solutions Through New Installation and Burial Approaches. SubOptic '97. San Francisco. P 750-757.

Return to Contents List

2 EXPLANATION OF BURIAL FEASIBILITY METHOD

The burial assessment predictions are provided in Appendix 1. Burial predictions are based on the following Route Position Lists

- *Havhingsten_S1.1_BU Port Erin - BMH Loughshinny_PSR03_29 April 2019*

If the installation is conducted to a different RPL, the KPs referenced in this report might be slightly incorrect.

The various components of the report are examined and described in more detail in Sections 2.1 through 11 below.

2.1 Classification of Seabed Types

Seabed lithologies identified by the survey have been classified as shown in Table 2-1.

Table 2-1: Seabed Type Classification

Sediment Type	Shear Strength, C_u (kPa)	Relative Density, D_r (%)	Sediment Description
I	<10 - 20	<15	Very Soft, Low Strength CLAY/SILT Very Loose SAND/SILT
II	20 - 40	15 - 35	Soft, Low Strength CLAY/SILT Loose SAND SILT
III	40 - 75	35 - 65	Firm, Medium Strength CLAY/SILT Medium Dense SAND/SILT
IV	75 - 150	65 - 85	Stiff, High Strength CLAY/SILT Dense SAND/SILT
V	150 - 300	85 - 100	Very Stiff, Very High Strength CLAY/SILT Very Dense SAND/SILT
VI	>300	>100	Extremely High Strength CLAY/SILT Weak rock, weathered bedrock or indurated/partially cemented sediment
VII	-	-	Rock

2.2 Trenchability

The route has been assigned five trenchability categories—A through E. These categories are described in Table 2-2.

Table 2-2: Trenchability Classification

Trenchability Class	Criteria
A **FULL PLOUGH BURIAL**	Full plough cable burial expected to target cover depth of 1.5m • *Extremely low to medium strength clays and up to medium dense sand/silt* • *BPI =0.60-2.0 in V Soft to Firm clay & = ~1.5 in med dense sand* • *Generally flat seabed (no sedimentary bedforms; low slopes)* • *Clays—shear strength >5kPa (no plough sinkage expected)* • *Constant burial conditions with low variability* • *Tow tensions generally low and consistent - <20T* • *Low plough pitch/roll expected* • *Optimal plough progress rate* • *Low plough share tip wear rate*
B **REDUCED VARIABLE PLOUGH BURIAL**	Target burial cover depth might not be achieved due to seabed conditions. Reduced cable cover depth predicted, ≤1.5m but >0.5m • *High to very high strength clay and medium dense to dense sand/silt; where loose/low strength sediment sits over a dense to very dense unit, which lies within the burial depth; or where rock sits within the burial depth* • *Burial Protection Index = 0.75-2.0 in high strength clay & = 0.5-1.5 in dense sand* • *Minor sedimentary features/seabed topography; slopes are generally <10°* • *Variable burial conditions possible, but >0.5m deep* • *Tow tensions generally 20T to 50T, but occasional high tensions >50T with high variability and possible renders.* • *Increased plough pitch and roll possible* • *Reduced plough progress rate likely* • *Medium to high plough share tip wear rate*
C **POOR VARIABLE PLOUGH BURIAL**	Poor burial, to a predicted ≤0.5m cover depth • *Very to extremely high strength clay and up to very dense sand/silt; or where a thin unit of loose/low strength sediment sits over a dense to very dense unit/rock that could reach the upper 0.5m of the seabed.* • *Burial Protection Index = <0.5* • *Complex seabed topography and variable conditions, consisting of rock or coral outcrop/shallow subcrop, high relief bedforms, boulders, seabed debris* • *Slopes are generally <10-12° downslope, 12-14° upslope, or 6° sideslope.* • *Poor/variable burial expected—generally <0.5m deep* • *Possible spot plough rideouts* • *Possibility for areas of cable very close to the seabed* • *Tow tensions likely to exceed 50T, with high variability and possible renders* • *High plough pitch/roll events possible* • *Slow plough progress rate* • *High plough share tip wear rate*
D **UNPLOUGHABLE**	Not ploughable, due to seabed conditions or route design criteria • *Complex seabed topography and variable conditions, consisting of rock or coral outcrop/very shallow subcrop, high relief bedforms, boulders, seabed debris* • *Seabed slopes generally >10-12° downslope, 12-14° upslope, or 6° sideslopes*
E **PLOUGH OVERBURIAL**	Uncontrolled cable overburial, ≥1.5m • *Thick, extremely low strength clay, with low seabed bearing capacity; shear strength <5kPa.* • *Burial Protection Index = 0.5-1.0* • *Plough sinkage and uncontrolled cable overburial possible* • *Low, consistent tow tensions, generally <20T* • *Low plough share tip wear rate*
SE	Surface Lay • Post lay burial required for shore end section

Trenchability Class	Criteria
IS	Surface Lay • Post lay burial required for existing infrastructure crossing of cables, pipelines, power cables
BU	Surface Lay • Post lay burial required following Branching Unit integration

2.3 Plough Tow Forces

The predicted plough tow forces are incorporated in the trenchability classifications outlined in Table 2-2 above. Table 2-3 below provides more information on these tow forces.

Table 2-3: Plough Tow Force Classification

Classification	Criteria
Low	Tow force less than 20 Tonnes (200kN)
Medium	Tow force 20 to 50 Tonnes (200kN to 500kN)
High	Tow force might exceed 50 Tonnes (500kN) • *High variability and possible DP slowdowns and renders*

2.4 Plough Wear Rates

Plough wear rates are related to the abrasiveness of the seabed sediments through which the plough passes. Table 2-4 summarises the wear categories used in the burial feasibility.

'Maintenance' is assumed to mean: share wear tip replacement, potential re-welding of new wear-plates on the share, skids, stabilisers, depressor and share guides, along with general checks for corrosion and coherency of corrosion-insulation materials.

Table 2-4: Plough Wear Rate Classification

Classification	Criteria
Low	Extremely low to low strength CLAY/SILT or very loose to loose SAND/SILT • *Plough recovery unlikely to be needed for maintenance reasons*
Medium	Medium to very high strength CLAY/SILT or medium dense to very dense SAND/SILT, • *Plough recovery unlikely to be needed for maintenance reasons*
High	Hardground/rock within the burial depth, or boulder areas • *Plough recovery likely needed every 50km for plough maintenance*

2.5 Plough Tow Speeds

Table 2-5 summarises the plough tow speed classification used in the Burial Assessment table. Predicted plough tow speeds have assumed a standard installation vessel, which has sufficient vessel power/bollard pull for a HD plough and the ability to maintain a constant speed while ploughing.

Table 2-5: Plough Tow Speeds

Speed	Criteria
Low	• <0.17-0.25m/s (<600-900m/hr) • *Type V or VI seabeds (Table 2-1)* • *Very high strength/very dense sediment or heterogeneous/layered seabeds; thin surficial sediment over subcropping rock; or a thin layer of loose/soft sediment sitting over a very dense/hard sediment layer*
Medium	• 0.25-0.50m/s (900-1800m/hr) • *Type III or IV seabeds (Table 2-1)* • *Relatively homogeneous sediment; medium dense to dense unlayered sand or medium to high strength unlayered clay* • *Or relatively short sections of otherwise high speed ground, in which it is not possible to get the plough up to its optimal speed*
High	• >0.50m/s (>1800m/hr) • *Type I or II seabeds (Table 2-1)* • *Thick, homogeneous extremely low to low strength clay or very loose to loose sand*

2.6 Burial Cover Depth

The target burial cover depth (depth below mean seabed) is 1.5m.

In general, burial depth predictions are based on known plough behaviour under given seabed conditions, and on:

- Seabed geology and its lateral variability
- Sediment lithology and geotechnical properties—shear strength/relative density
- Seabed topography—seabed slopes, sedimentary bedforms, pockmarks/depressions
- Obstructions (sonar contacts)—natural or manmade

The classification for burial depth categories is shown in Table 2-2.

Please also see the note on target burial depth, predicted burial depth and the Burial Protection Index, in Section 1.2.

2.7 Installation Risk Assessment

The Installation Risk Assessment (IRA) score shown in Table 2-6 refers to the safety of the burial equipment during the cable lay operations. The burial equipment is primarily a seabed plough, although a remotely operated vehicle (ROV) is sometimes used to conduct post-lay burial (PLB). Table 2-7 provides a summary of the typical risk elements that can lead to IRA 2 (MBC) or IRA 3 (Surface Lay) designation.

Table 2-6: Installation Risk Assessment (IRA) Score

Installation Risk Assessment (IRA) Category	Risk Assessment Conditions
1 *Low Risk*	PLOUGHABLE/PLB ATTEMPT *No significant risk to the burial equipment due to seabed conditions*
2 *Moderate Risk*	MARGINAL BURIAL CONDITIONS (MBC) *Identified risk to the burial equipment due to seabed conditions; potential damage repairable onboard, using shipboard spares. A plough/PLB attempt will be made.*
3 *High Risk*	SURFACE LAY/UNPLOUGHABLE/NO PLB ATTEMPT *High risk to the burial equipment due to seabed conditions; potential severe damage not repairable onboard using shipboard spares*

Table 2-7: Typical Risk Elements Leading to IRA 2 or 3 Designation

Category	Marginal Burial Conditions (MBC) Element	Seabed Conditions	RPL Abbrev'n
IRA 2 *Marginal Burial Conditions*	*Sediment*	Extremely Low Strength Clay (<5kPa) on Slopes—plough sinkage and uncontrolled cable overburial possible. Low traction on slopes, potential loss of plough control, especially in deeper water.	**MBC (SS)**
		High Strength Sediment—dense to very dense granular sediment (sand/silty sand), with relative density (RD) >85%; or stiff to very stiff cohesive sediment (clay) with shear strength >150kPa. Reduced burial possible, with high tensions and potential renders.	**MBC (HT)**
		Hardground—at the seabed or within the burial depth. Hardground is partially indurated (cemented) sediment or very weathered rock (>95% RD in granular sediment, or >300kPa in cohesive sediments). Difficult burial conditions and plough damage possible.	**MBC (HG)**
		Rock Subcrop—rock sitting within the target burial depth. Reduced burial expected and the potential for high tensions, renders and plough damage, depending on the roughness of the buried rock surface.	**MBC (SR)**
	Slopes	Increased Topography—slopes regularly >8-10°, or sideslopes >4°.	**MBC (SL)**

Category	Marginal Burial Conditions (MBC) Element	Seabed Conditions	RPL Abbrev'n
IRA 2 *Marginal Burial Conditions*	*Seabed Features*	Seabed Depressions—moderately dense, >1m deep, but with marginal sidewall slopes and the potential for plough sinkage in sediment <5kPa. Possible avoidance using plough's forward-looking sonar.	**MBC (SB)**
		Sediment Bedforms—sandwaves >3m in height, and/or with crests aligned parallel or sub-parallel to the route.	
		Rock/Coral Outcrops—within half water depth of the route.	
		Boulders/Other Sonar Contacts—>0.5m high, within half water depth of the route.	
	Surface Currents	Strong Surface Currents—consistently >1-2m/s.	**MBC (SC)**
IRA 3 *Surface Lay* *Not Ploughable* *No PLB*	*Sediment*	Rock Outcrop—rock sitting at the seabed.	**PLUP/PLDN** half water depth either side of the feature
	Slopes	Complex Topography—downslopes regularly >12°, upslopes >14°, sideslopes >6°.	
	Seabed Features	Seabed Depressions—unavoidable, dense, large, deep features with unploughable sidewall slopes and the potential for plough sinkage in sediment <5kPa.	
		Rock/Coral Outcrops—unavoidable and very close to the route.	
		Boulders/Other Sonar Contacts—>0.5m high, unavoidable and very close to the route.	

2.8 Seabed Gradient Classification

The following table defines the categories for describing the seabed gradients encountered along the route.

Classification	Gradient (degrees)
Very Gentle	<1
Gentle	1 – 4.9
Moderate	5 – 9.9
Steep	10 – 14.9
Very Steep	>15

2.9 Classification of Seabed Sedimentary Structures

Areas of shallow water with high current velocities can often have associated seabed features such as ripples, megaripples and sandwaves. The one of most concern for installation are sandwaves. These can be several metres high and if crossed obliquely cause plough stability problems. Crossing perpendicular can also cause problems as the plough transits over the crest and then has a steep descent putting extra strain on the cable causing it to become exposed if not enough slack is inserted.

The following tables defines the sizes of these features.

Structure	Wavelength (metres)
Ripple	<0.5
Megaripple	0.5 - 25
Sandwave	>25

2.10 Marginal Burial Conditions (MBC) Areas

Areas of the route designated within the RPL as 'Marginal Burial Conditions' or 'MBC' denote that conditions are borderline for plough or ROV operations, due to the presence of steep up, down or side slopes, hard or very soft sediment conditions, gas/hydrothermal release features, subcropping rock or other seabed irregularities. It is intended to attempt burial in these areas; however, in the event that conditions become unjustifiably hazardous to the plough or cable, the Master and Subsea Team Leader will, at their discretion, relocate the plough and recommence burial where the seabed conditions show improvement. Hazardous conditions include but are not limited to: damage to the plough, plough runaway, uncontrolled plough sinkage, very high tow tensions/renders, highly variable plough pitch/roll in rough topography or steep slopes, and the inability to prevent the plough tow wire from interacting with the cable. Table 2-7 provides a more detailed list. Such plough skips will not be subject to any post lay burial attempts because the conditions as found by the plough will be equally hazardous to the burial ROV and may result in damage to the cable.

2.11 Notes on Using the Burial Assessment

The Burial Assessment table, Appendix 1, provides professional-judgment level predictions of the burial conditions likely to be experienced during the installation. The following points list some general assumptions made during report compilation, along with points that should be understood when using the Burial Feasibility table.

- **Based on RPL version** Havhingsten _S1.1_BU Port Erin - BMH Loughshinny_PSR03_29 April 2019. KP references in the report might be slightly inaccurate if the installation RPL differs from this version.

- **Predictions are subject to inherent inaccuracies**—the predictions are based only on available geotechnical data, which is limited to discrete, spot locations,

and on marine geophysical survey data. This is why there are bridging categories in the report (e.g., A/B) when conditions are not expected to be steady state.

  - Predictions are based on extrapolations between single geotechnical data points, as provided by CPTs and physical seabed samples. Summaries of the CPTs and Sediment Samples can be found in Appendix 2.

- **Burial conditions can never be described definitively**—the burial depth and tow tensions experienced during the installation can, given the exact same seabed conditions, vary by altering the plough speed and share/trench depth settings. It is difficult to express the potential for this type of real-time change in Appendix 1

- **Burial categories are protective**—because it is difficult to provide a definitive burial condition, as described in the bullet point above, burial predictions in Appendix 1 are written as worst case scenarios, in order to be protective to the cable system.

Return to Contents List

3 PLOUGH MAINTENANCE POSITIONS

No unplanned plough recoveries should be required for plough maintenance due to the relatively short length of this segment and the fact that it is almost entirely in low wear rate, very soft to soft clay sediments.

Return to Contents List

APPENDIX 1 BAS SUMMARY

See Separate File

APPENDIX 2 CPT & SEDIMENT SAMPLE LOGS

See Appendix G & H of Main Survey Report