Geotechnical Support Services - Hywind Scotland Offshore Windfarm

Landfall Site Walkover - Geotechnical Evaluation

Statoil ASA

Assignment Number: A100142-S01
Document Number: A-100142-S01-TECH-001

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Client: Statoil ASA
Document Type: Technical Note
Document Number: A-100142-S01-TECH-001

Rev	Date	Description	Issued by	Checked by	Approved by	Client Approval
A01	02/04/15	Issued for Use	AT	LF	LF	
R02	26/08/2013	Client Comments Incorporated	GCO	SED	SED	
R01	23/07/2013	Issued for Client Review	GCO	CGO	SED	

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1 INTRODUCTION

Statoil ASA are planning to develop an offshore wind farm Pilot Park approximately 25 km to the east of Peterhead on the Aberdeenshire coast covering an area of approximately 60 km2. The Pilot Park will be located either to the north or south of the BP Forties C to Cruden Bay Pipeline, which runs through an Exclusivity Area associated with the development. The Pilot Park will consist of 5 turbines that will be up to 6 MW in size (30 MW maximum). The turbines will have a maximum height of 101 m with a rotor diameter of up to 154 m maximum and a draft of 80 m.

The Pilot Park will export energy via a power cable to shore at a proposed landfall location, with 3 No. options being considered north of Peterhead Harbour, as shown in Figure 1 below. The proposed offshore export cable route options are presented in Figure 2 with possible substation locations marked in red.

The scope of this document is to present the findings from a brief engineering geological site walkover of each proposed landfall location to understand the geomorphological and technical constraints each site offers. The walkover was performed on 16th July 2013 between 11:00 – 13:00 during low tide.

Figure 1: Proposed cable landfall locations – 1, 2, and 3. Base Case landfall is Site 2.

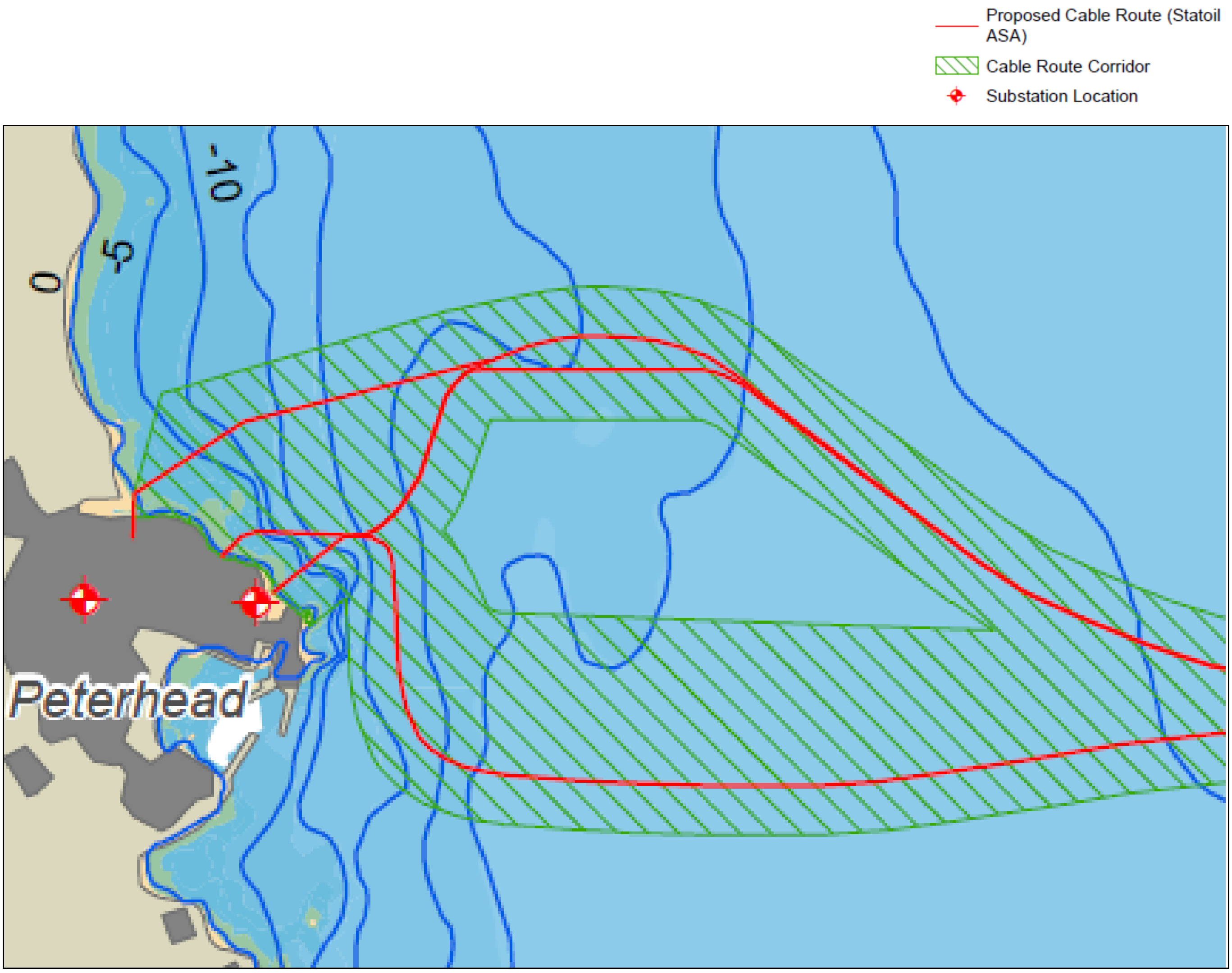

Figure 2: Proposed export cable route options to the landfall options. Note the offshore cable route selected is most likely the northern option.

2 SCOPE OF WORK

An engineering geological site walkover of each site includes:

- geographical evaluation,
- geomorphological assessment,
- qualitative geotechnical appraisal of soil/rock conditions, and
- develop an understanding of the constructability of each location.

2.1 Methodology

The methodology adopted for the site walkover involved:

- evaluating aerial photography images,
- annotated sketches of features and hazards in the area,
- photographs of the sites from various attitudes, and
- notes of features inherent to each site

A list of general site inspection type criteria was used to fill in the technical observations of each location to understand how the construction issues affect site selection.

Out of the 3No. sites indicated in Figure 1, only one is considered to be viable at this stage, which is Site 2. The other two landfall locations were looked at, but less time was spent there investigating the shoreline.

3 LANDFALL CONSTRUCTION TECHNIQUES

In carrying out the landfall site evaluations, requirements of the typical methods of construction need to be considered. Typically, two methods of construction are used for cable landfalls, which are Open Cut Trenching (OCT) and Horizontal Directional Drilling (HDD). The decision on the most appropriate method depends on the site conditions, such as environmental, topographical, geological/geotechnical, and cost constraints. For the most part, the cable is required to be buried below existing ground/seabed conditions at the landfall site for protection, to ensure environmental and economic security of the asset.

The offshore/onshore interface is usually located onshore above the high water mark that extends inland to a suitable location at the point of connection to the distribution or transmission grid. For this project, the inland location would typically be based on shoreline topography, geology, cable properties, and environmental/ consenting constraints.

3.1 Open Cut Trench

For sea to shore landfall construction, the OCT method requires the excavation of a trench which is then back-filled following installation of the cable. For landfalls the trench is generally divided into two sections which consider an onshore portion and an offshore portion. Standard land based techniques can be employed for the onshore section of work, but specialist dredging/trenching equipment would be required for the offshore section to successfully protect the cable below the high energy littoral zone (i.e. surf). The primary purpose for landfall design and construction is safe burial of the cable to offer complete protection from environmental and mechanical activities, and to ensure it is not exposed during the operational lifetime.

The depth of excavation is dependent on site morphology and coastal processes, and that the open trench will be able to remain stable and 'open' long enough to achieve the cable installation before burial. If site conditions do not allow this then temporary trench support is required, usually in the form of steel sheet piling for cofferdam construction (see Figure 3). These are often require a burial depth of up to 3.0m below lowest expected beach level, to take into account long-term variations in beach profiles and in consideration of the security of the cable.

Figure 3: Example of a sheet piled cofferdam often used for cable pull operations at landfalls

Once a trench has been formed, the offshore cable can be installed from the cable lay vessel by a combination of floating and pulling the cable ashore using a pulling head from a land-based winch (see Figure 4). Therefore, additional consideration to the approach from offshore also needs to be looked at for landfall site suitability.

Figure 4: Example of a cable lay vessel linked to a shore approach at a beach landfall

3.2 Horizontal Directional Drill

In coastal areas that do not allow OCT to be formed, HDD is the alternative method to install cables from sea to land. HDD involves drilling a hole at depth through the ground between two points between which the cable will be installed; these are referred to as the entry and exit points, with the drilling rig being set up at the entry.

For cable installation a solid conduit is normally installed first and the cable pulled in afterwards. Proper selection of downhole tools including bits, reamers/hole openers, specialized tools and cable pulling devices is critical to the success of an HDD installation. Therefore, the subsurface geology and geotechnical conditions, size of product, and length of bore are the main considerations in the selection of the equipment to be utilised on the project. Additionally, because a borehole is to be drilled, drilling muds are required to assist in maintaining the integrity of the hole and to transport the cutting material out of the hole as drilling progresses. Careful choice of the correct drilling mud and any additives required should be selected on the basis of drilling performance and environmental constraints identified at each site.

There are two main options for the HDD work depending on the mechanical properties of the submarine cable and the shore and nearshore conditions to be drilled under. These include:

- a ‘short’ HDD, which bores under cliffs to exit at some point on the beach between high and low water. The shorter HDD would rely on suitable access to the beach for construction of the beach OCT.
- a ‘long’ HDD duct allows the cable to be installed under both the intertidal littoral zone and sea cliffs to a point offshore. This may also be conducted from sea to shore using an offshore HDD, but either option allows no requirement for access to the beach.

Further description of both is presented below.

3.2.1 Short HDD

A landfall constructed using short HDD means the exit point is on the beach, which necessitates beach access for OCT construction activities. Two construction methods are therefore required for the landfall, and further consideration must be given to the design depth of cable and construction techniques to be employed on the beach. The interface between the HDD and the OCT methods requires careful design to consider the removal of buoyancy attachments before post-lay burial operations can commence. This method is dependent on having a suitable area for OCT construction to connect to.

3.2.2 Long HDD

For long HDD operations, the land based drill rig would be located above the high water mark some distance back from the coastline in order to ensure that the final profile is suitable for the lifetime of the project. Coastal processes especially erosion profiles of cliffs and debris deposition on beaches, needs careful evaluation. The exit point offshore is dependent on several issues, which include performing a comprehensive evaluation of cable length that can be pulled through the conduit without exceeding the minimum breaking load of the cable; assessing the stand-off position of the cable lay vessel offshore with the known water depth; and predicting the drilling profile of the bore (curvature) to suit the subsurface conditions. Each of these are key elements to be evaluated during detailed design using geotechnical and bathymetric data, and from the known cable properties. A typical working estimate for maximum length of cable pull is 500 m – 1000 m.

The method of long HDD is often used to avoid problematic areas suffering from significant coastal erosion and unstable cliffs, or where cliffs are high and inaccessible, which would represent a health and safety issue during construction.

If land based long HDD is evaluated to be unsuitable, then consideration of sea-to-shore HDD using an offshore jack-up rig presents another option, but at much more expense due to the associated vessel costs. The operation is effectively identical to the land based long HDD, but with interchanged entry and exit points.

4 SITES

4.1 Landfall Site 1

An aerial photograph of Site 1 is shown in Figure 5 below. Note this site may not be considered feasible due to local fisherman concerns and local recreational amenities being close to the foreshore.

Figure 5: Landfall Site 1 – numbers refer to photos

4.1.1 Evaluation

Item	Comments
Site Description	Sandy and rocky beach that extends out 50 – 100m from the promenade (photo 3). Rocky outcrops are less evident closer to the mouth of the river as indicated in Figure 5. Extensive sand beach on north side of river adjacent to golf course. Note, the northern side of the river was not part of the investigation, so further discussion of this area is not presented. On the eastern margin of this area, there is a small concrete jetty/breakwater used by local fishermen (photos 1 and 3). A 20 – 30 m wide inlet for landing fishing boats lies on the

	western side of the jetty and is laid with silty sand sediments. The thickness of such is unknown, but likely to be shallow (< 1m thick over rock/gravel). The jetty has formed a breakwater to protect the boats tied alongside and hence the energy within the bay is significantly reduced; hence the ability for sand and silt to deposit. West of this inlet is a rocky shoreline that extends out approximately 150 m. An openly corroded and exposed concrete water discharge pipe/conduit (< 400mm diameter) lies just west of the inlet that was constructed out to sea. Water still discharges at the base of the seawall where the pipe exits. The sandy area to the west was not investigated further, as this unlikely to be an available option due to local recreational/fishermen constraints.
Geology	Granite basement rock that is well jointed, but very competent.
Geomorphology	Shoreline consists a shelf of basement rock that becomes more sandy west toward the river mouth. The beach area is very gently sloping. The river channel across the beach during the day of the site visit extended towards the east and entered the sea where the rocky substrate becomes more apparent. The land behind the beach and above the promenade is an engineering embankment covered in grass. Behind this is residential housing and a football field.
Shore Protection	Concrete seawall approximately 3 - 4 m high.
Land Instability	None. Beach area has concrete seawall that mitigates coastal erosion and no evidence of slope movement in the soil banks adjacent to the beach promenade was observed.
Landuse	Residential/Recreational. Small fishing jetty may have commercial activity.
Landfall Approach	Conventional open-cut trenching/cofferdam would be feasible at the sandy beach; however this is highly unlikely to be allowed due to local fisherman activity and recreational use of the area, as open-cut trench cable pull operations would cause major disruption. However, conventional open-cut trenching/cofferdam would not be feasible on the rocky beach without major construction activities being adopted (e.g. drill and blast and mechanical excavation). Additionally, consideration to building a conduit across the rocky foreshore out to sea to protect the cable would be very conspicuous and unlikely to be given consents. Laying the cable on the rock would make it exposed to high energy environmental loadings, abrasion and dangerous exposure of a high voltage cable to recreational users of the shore. A potential option is to use a long HDD (horizontal directional drilling) approach from the flat grassed areas adjacent to the promenade parallel to Churchill Drive. The length of the HDD would only need to be a few hundred metres out to a safe location offshore (away from fishing and recreational activity). However, this would need further evaluation from an HDD contractor.

4.1.2 Recommendations

Statoil indicate that this Site is currently an unlikely option due to current coastal shore use by local fishermen and recreational users. However, technically this would be the best placed to perform a conventional low risk and cost-effective landfall cable pull operation either on the sandy beach or up the inlet of the fishing bay, as this zone is protected by the concrete jetty.

Photo 1

Photo 2

Photo 3

4.2 Landfall Site 2

An aerial photograph of Site 2 is shown in Figure 6 below. Note this site is the base case cable landing location.

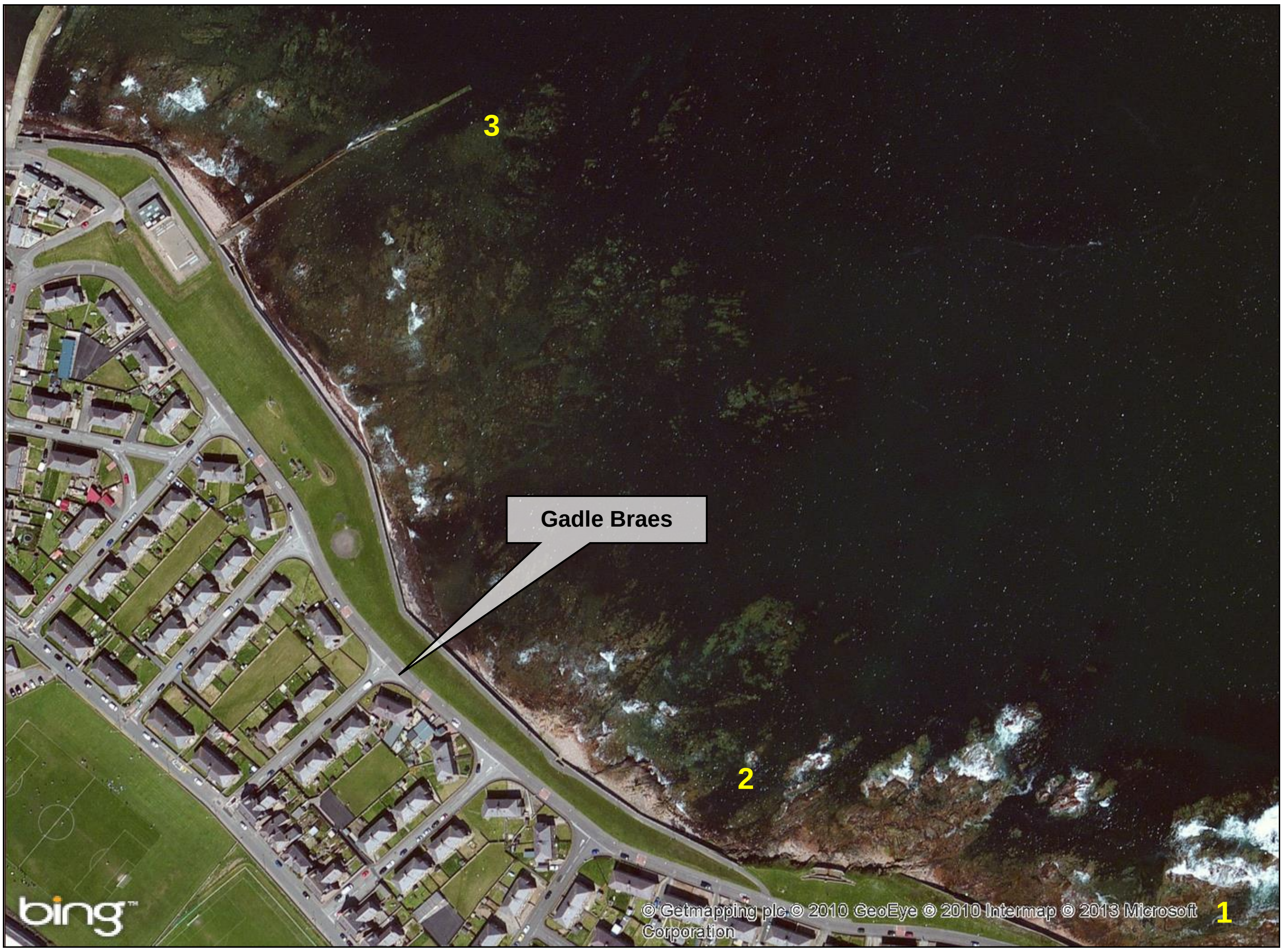

Figure 6: Landfall Site 2 - numbers refer to photos

4.2.1 Evaluation

Item	Comments
Site Description	The shoreline at this site is a rocky shelf that extends out approx. 100 – 150 m from the base of the concrete seawall. Pockets of coarse gravel/cobbles/boulders fill low spots on the rocky shelf. No beaches exist along this area, except for small accumulations of coarse gravel/cobbles. The site is approximately 700 - 800m long lying between a concrete water treatment outfall conduit in the west (see Figure 7) and the start of an industrial estate to the east. The concrete conduit extends out approx. 150 – 160 m from the base of the seawall, which is connected to a fenced off water treatment plant owned by Scottish Water. Above the seawall is the continuation of the promenade from Site 1, but this ends approx. 2/3's along the site to the east where it rises to the road (Gadle Braes). The land uphill of the seawall consists of a grassed bank that has a residential road built along its crest. A

	children's playground and a memorial site also exist along this promenade. Some disused wire cables anchored to the seawall and partially covered in concrete on the rock shelf are exposed. Use is unknown.
Geology	Granite basement rock that is well jointed, but very competent.
Geomorphology	Shoreline consists of a shelf of basement rock that is irregular in outcrop (i.e. rough terrain) and appears to have more mobile cobbles and boulders lying toward the western section near the water treatment conduit. The rock jointing has allowed some narrow gravelly/cobbly inlets to be formed through erosion, but these are limited in width to < 10 m across. The grassed bank above the promenade is an engineering embankment with residential housing and a football field beyond.
Shore Protection	Concrete seawall approximately 4 - 5 m high.
Land Instability	None. Beach area has concrete seawall that mitigates coastal erosion and no evidence of slope movement in the soil banks adjacent to the beach promenade was observed. Only erosion of the soil near the memorial site was evident, but this is more attributed to surface run off and pedestrian traffic to the shore.
Landuse	Residential/Recreational. Some industrial areas lie in the eastern part of the site and behind the houses.
Landfall Approach	Conventional open-cut trenching/cofferdam would not be feasible on the rocky beach without major construction activities being adopted (e.g. drill and blast and mechanical excavation). Additionally, consideration to building a conduit across the rocky foreshore out to sea to protect the cable would be very conspicuous and unlikely to be given consents. Laying the cable on the rock would make it exposed to high energy environmental loadings, abrasion and dangerous exposure of a high voltage cable to recreational users of the shore. The best option would be to use a long HDD approach from a flat grassed area adjacent to the promenade parallel to Gadle Brae (most likely to the western margin near the playground where the grass embankment is wider and of a shallower slope). The length of the HDD would only need to be a few hundred metres out to a safe location offshore. However, this would need further evaluation from an HDD contractor.

4.2.2 Recommendations

The foreshore is too rocky and coarse to pull a cable up to a land connection; therefore underground techniques such as HDD would need to be adopted to consider a safe and effective cable connection, rather than construction above ground which is much more visible and will leave a permanent mark on the shore.

Photo 1

Photo 2

Photo 3

4.3 Landfall Site 3

An aerial photograph of Site 3 is shown in below. Note this site may not be considered feasible due to consenting issues.

Figure 7: Landfall Site 3 - numbers refer to photos

4.3.1 Evaluation

Item	Comments
Site Description	This site is bound by a natural rocky shore and in between is a man-made erosion protected coastline in front of an industrial estate. The shore protection consists of large 2 - 3 m^3 granite boulders and some formed concrete protection structures in front of a high 4 - 5 m concrete seawall. Behind the seawall is Alexandra Parade. A concrete conduit structure exits below the rip rap protection approx. at the halfway point between the natural rock outcrops to the west and east (aligned with Albert St). The conduit has two exit points, but a close-up inspection was not performed at the time. It is unsure what the conduit discharges or is used for, and if there are other access points to it. Note, the area of Alexandra parade and the Port Henry Pier is constructed on engineered fill, as originally this area was a narrow seaway passage separating Peterhead township and Peterhead Peninsula. To the west of the alexander parade is the rocky seashore adjacent to The Esplanade. The

	eastern side of the shore is partially covered in large rip-rap type granite boulders against the concrete seawall that is 3 m high from the rocky shore, but only 1.0 - 1.5 m high at pedestrian level on The Esplanade. Behind The Esplanade is residential estate.
Geology	Granite basement rock that is well jointed, but very competent.
Geomorphology	The western shoreline consisting mainly of a shelf of basement rock is irregular in outcrop (i.e. rough terrain) and consists distinct rock jointing and dyke-type structures that has allowed some narrow inlets to be formed through erosion. These inlets are often filled with coarse gravel/cobble/boulder type sediments and are limited in width to < 10 - 15 m across. The manmade shoreline is straight, flat and well protected from the sea. The industrial area is heavily built upon with sheds, car parks, and loading bays.
Shore Protection	Large boulders of granite rock (rip-rap) and a high concrete seawall approximately 4 - 5 m high.
Land Instability	None as the natural shore is a rocky shelf with slopes, and the man-made area consists heavy coastal erosion protection measures
Landuse	Residential/industrial.
Landfall Approach	Conventional open-cut trenching/cofferdam would not be feasible on the natural rocky beach without major construction activities being adopted (e.g. drill and blast and mechanical excavation), or along the man-made section. Laying the cable on the rock would make it exposed to high energy environmental loadings, abrasion and dangerous exposure of a high voltage cable to recreational users of the shore. Additionally, on this western rocky shore section houses are located on The Esplanade opposite the seawall, which makes it difficult to locate any construction operations for the landfall without major disruption. However, there are a couple of options: 1. Consideration of long HDD from the industrial estate under the seawall and out to sea. There are several flat areas that are empty (e.g. car parks) to set up the drilling equipment to push a conduit out to a safe exit point offshore. The length of the HDD would only need to be a few hundred metres out to a safe location offshore. However, this would need further evaluation from an HDD contractor as the site is built on engineered fill and the depth to natural rock may vary significantly knowing that this site was built upon a natural seaway channel. 2. Pull the cable up the existing concrete conduit that lies in the middle of the Alexandra Parade opposite Albert St. However, further consultation with Peterhead Council and/or Harbour Dept. would be needed to understand what the conduit is and if such an operation is feasible.

4.3.2 Recommendations

The foreshore is too rocky and coarse to pull a cable up to a land connection; therefore underground techniques such as HDD should be investigated to consider a safe and effective cable connection. Construction above ground is much more visible and will leave a permanent mark on the shore, is such an operation is considered.

Further understanding of the ‘fill’ area between Alexandra Parade and Port Henry Pier would be needed to understand what lies beneath the surface if underground cable pull operations are to be investigated further for this site.

1

2

3

5 DISCUSSION

Based on the site walkovers investigating site topography, coastal geology and general marine environment, a long HDD method of cable landfall construction and installation is considered the a suitable technique to adopt for Sites 2 and 3, and some of Site 1 if the sandy beach areas cannot be accessed for conventional OCT. The ground conditions and geology observed along this coast are observed to be reasonably consistent, in that the foreshore consists of competent granite bedrock, and the beach areas above high contain gravelly sandy soil, or fill type material (i.e. grassed verges). To prove the suitability of setting up and HDD base platform to initiate and drive the drilling, an onshore geotechnical survey at suitable sites would need to be performed and evaluated by an HDD contractor to understand the materials to drill and the method used to create a stable hole to pass the cable through (i.e. cased or no casing required). Trial pits and borehole surveys (e.g. rotary drilling or cable percussion techniques), and possibly onshore geophysical surveys (shallow seismic, resistivity, ground penetrating radar, etc.) will form part of this survey.

The onshore site investigation(s) is required as part of the engineering evaluation of the subsurface rock to understand competency and confidence of drilling operations at the site. This may involve drilling a borehole to 30 - 50 m depth to quantitatively and qualitatively assess geotechnical properties of the rock material and rock mass (e.g. unconfined compressive strength and RQD (rock quality designation) of cores samples). Trial pits would be used to investigate the platform on which to found the HDD drilling operation, which may be integrated with some geophysical survey if the ground conditions are thought to be complicated (i.e. layered soils, underground infrastructure, etc.). Initial geotechnical site investigations would be performed above the high tide mark in areas that are readily accessible by a wheel- or track-mounted rig unit, of which there are several locations along all three sites. Obviously consents will need to be applied for before such investigations can be made.

At the moment, the decision to go ahead with HDD cannot be made without further information from the nearshore surveys of the cable routes to understand the nature of the seabed where the drill is to exit. However, based on the site reconnaissance, the granite bedrock was observed to be competent enough to successfully drill at depth (i.e. 10's of metres below surface), but further investigation into joint structure attitude should be evaluated to see if this will have an impact on directional drilling orientations. Additionally, the offshore bathymetry of the cable route needs clear definition to allow accurate location of the exit point out of the seabed in a favourable and safe manner.

Typically, HDD machines are heavy, run on tracks and will disturb or damage the area below them or where they transit. For the most part, long HDD construction will require excavation around the set up location to prepare a level platform and provide access where utilities need to be connected (e.g. generator, water pump and associated tank (if required)). Depending on the location where the HDD is to drill from, construction of the main access track to the site would involve smoothing and potentially cut and fill excavations to ensure the ground is competent enough to carry the weight of the tool and associated support utilities. Ground preparation would be required to ensure a stable platform is created to support the tool itself, which may involve constructing an engineered pavement. However, after completion of the work all ground disturbances would be reinstated and landscaped back to the original or desired topography. An example of a typical HDD set up is presented in Figure 8 and Figure 9 (from Land and Marine Ltd and Stocktans Drilling Ltd. websites).

Figure 8: Typical short/long HDD drilling tools (Land and Marine Ltd).

Figure 9: Long HDD drilling for a landfall (Stocktan Drilling Ltd).

As with all methods of land construction and excavation (e.g. building access roads, levelling ground, clearing areas for temporary support facilities, such as water tanks, etc.), there is still damage to the environment that needs to be carefully managed through proper planning and risk analysis to keep it to a minimum. This includes managing water used for the boring and what comes out of the borehole if close to sea level. Generally, this usually causes minimal disturbance, but in environmentally sensitive areas, the vegetation and wildlife need to be protected.

Additionally, depending on the subsoil conditions located in the area of the HDD landfall, tidal influence on the hole integrity of the HDD operations may require further consideration. If the hole is not cased and the soils allow for tidal waters to enter the bored annulus then a flushing and dilution of the drilling mud may occur, which could affect drilling operations detrimentally, and could cause hole collapse or subsequent surface subsidence. This would result in significant delay and cost to remedy such an event. To mitigate and ultimately prevent this from happening, casing can be installed into the bedrock well below the tidally influenced zone.

A downside to HDD is that it is expensive. Based on other HDD landfall projects carried out recently in the UK, a long HDD project (approx. 600 m long drilling) can cost between £1.0M – £1.6M per borehole from a land driven operation. However, these costs are site specific based on site access, length of drilling operations, materials required for operations (e.g. casing), type of product to feed into the drilled hole, etc., so early contractor involvement is critical in establishing such costs. For marine driven HDD operations (more uncommon), the cost is much greater as an offshore barge or jack-up rig, plus associated tugs, would be needed.

6 CONCLUSIONS

Based on the brief site walkovers and for the purposes of this project, HDD landfall construction techniques are the preferred technical solution for the sites investigated rather than conventional OCT. The reasons for this are:

> HDD has the ability to avoid the issues surrounding the rocky coastal shelf by drilling beneath the surface and high energy littoral zone and that it can be used to connect one cable (or more cables as required) from a single location;

> This makes HDD a safer operation than OCT on the beach, and has less of an environmentally damaging footprint on the ecosystem and adjacent areas, especially in areas that are site sensitive to surface disruption;

> HDD should reduce the potential of any contamination to surface water and/or groundwater pollution if this as it can be controlled through the drilling operation;

> HDD general requires no major excavation and shoring costs at the beach compared to OCT methods; and

> HDD is not as weather sensitive compared to other excavation and pile driving techniques employed at the beach; however weather needs to be carefully monitored for the offshore phase when the drill-bit is expected to ‘daylight’ at the seabed, where the connection to the cable will require low sea states to perform that operation.