Landing Marine-derived Renewable Energy: Optimising Routing of Electricity Cables in the Nearshore to Offshore Environment

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Abstract

In a climate dictating an increasing need to route submarine cables through the nearshore environment either to bring marine-derived renewables ashore or to increase network resistance and resilience EirGrid Plc., the Transmission System Operator (TSO) for the Republic of Ireland, commissioned Mott MacDonald Pettit Ltd. to carry out a feasibility study into installing several nearshore cable crossings in Ireland.

Investigations were undertaken in order to consider the feasibility of installing proposed submarine high voltage power cables in the nearshore environment. The proposed crossing of the Shannon Estuary as part of a wider project to improve the capacity of the transmission network of the Republic of Ireland is used as an example throughout this paper.

Information regarding the geological ground model, meteo-oceanographic and archaeological conditions of the proposed site was limited, necessitating a clear investigation strategy. The investigation included gathering site information on tidal currents, bathymetry and geology through desk studies, hydrographic and geophysical surveys and an intrusive ground investigation.

The increasing frequency, need and importance of investigation and planning for submarine cable routes is discussed alongside potential methods for installation in the aggressive nearshore environment.

Background: the increasing requirement to identify suitable nearshore cable routes

Offshore cables or pipelines across rivers, estuaries, seas and oceans have historically been used in the power industry, telecommunications industry and the oil and gas industry. Recently the necessity to identify nearshore and offshore power cable routes has become increasingly prominent within the power industry. This development has been driven by the following factors:

- Transmission system interconnections. There has been an increasing prevalence of interconnections between different transmission grid networks. This has facilitated more resilient transmission systems, for example, EirGrid is in the process of connecting the transmission systems of the Republic of Ireland to the systems of Britain via the 'East-West Interconnector' Project. This will involve the installation of 250km of high-voltage direct current interconnector across the Irish Sea. Additionally transmission system interconnections offer opportunities either to import or export power generated between jurisdictions, in particular, this can provide a useful contingency for renewable energy sources, the majority of which provide energy at variable levels depending primarily on hydrodynamic and atmospheric conditions.

- Problems associated with traditional transmission system development. Due to the geographic nature of the west coast of Ireland the logical choice for transmission network reinforcement across an estuary such as the Shannon would tend towards a submarine cable installation as opposed to an overhead transmission line. The significant reduction in distance, approximately 3km of submarine cable as opposed to 30km of overhead line, indicates the necessity to thoroughly investigate the potential for such a submarine cable crossing of the estuary. The proposed Shannon estuary submarine cable crossing discussed within this paper is an example of such a connection which offers significant advantages over an overhead line.

- Developments in technology. The development of solid plastic insulation i.e. cross linked polyethylene (XLPE) for high voltage submarine cable applications has resulted in its increased use internationally at transmission system voltages. This has less environmental impact and is more economical when compared to the older paper or oil filled cable equivalents.

- An increased interest in marine derived renewable energy such as wave energy, tidal power and offshore wind farms. Locations which naturally lend themselves to high yield energy capture are, by definition, exposed and may be remote, far from the end user of the electricity generated. Key to effectively harnessing these resources is whether or not electricity generated in these high-energy, variable and constantly evolving environments can be brought safely and reliably to shore without requiring continual monitoring and maintenance of the subsea cables and landfall sites.

In the process of selecting a site for development of an offshore marine energy hub, it is rare for detailed consideration to be given to the cable route back to shore at an early stage. Of primary concern at the inception of such developments are potential impacts upon nearby amenity values, environmental issues or planning permissions required for the construction of associated infrastructure (e.g. a power station, substation or an offshore wind farm). These issues may be given even higher priority in the selection process than locating a site in ideal hydrodynamic or atmospheric conditions for harnessing power. Thus there can be tremendous pressure to find a suitable route for a cable in less than ideal conditions.

The Shannon Estuary Case Study

Mott MacDonald Pettit is linked with a number of cable routing studies in Ireland, some of which are in high-energy nearshore environments. The example discussed in this paper involves a cable crossing of the Shannon estuary in Ireland, from Moneypoint Power Station in the north to Tarbert Power Station in the south, crossing almost 3km of the tidal estuary.

Cable characteristics

The high voltage submarine cable type selected for use was a 220 kV, copper conductor, XLPE, single core cable, with extruded lead sheath and non- magnetic armour. Typically this cable would have an outer diameter in the order of 140mm and would have an approximate weight of 50 kg/m. The overall circuit to be commissioned was a three phase alternating current (ac) supply so a separate single core cable was required for each of the three phases. The spacing between each cable along the submarine route may be up to 50 metres wide to minimise the risk associated with failure due to a common cause such as a ships anchor and also to allow repairs to individual cables without disruption to the adjacent cables.

The submarine cable was to be buried along the entire length of the route. This would provide protection against damage from ship anchors and fishing activity. The target depth of seabed burial was 1.5 metres. This was to be confirmed by the survey and if it was not economically possible to bury the cable then consideration was to be given to covering with a protective layer of rocks or specialised cable mattressing, to a depth of 1 metre.

Survey requirements

In order to select the optimum cable route and determine the required cable characteristics, an accurate survey must be undertaken to gain a detailed understanding of the conditions that the cable must endure and to ensure the reliability and the protection of the cable (Herrouin and Scuiller 1995). The key aim of the study was to confirm the feasibility of the submarine cable circuit. The site investigation had to provide the right level of detailed site information to identify the optimum route avoiding any underwater obstructions or steep gradients whilst considering the installation methodology and the provision of sufficient protection for the cable to prevent slack spans or exposure. Other considerations within the survey were the environmental and archaeological impact of the cable. The survey needed to collect sufficient information to satisfy the statutory requirements in order to gain permission to install the cable. A detailed site investigation will also be key to submarine cable contractors who will be able to provide more accurate tender prices and installation methodologies at the tender stage.

When investigating the feasibility of routing a cable four stages of site work must be considered:

Stage 1: The survey. Is the equipment selected for the site investigation appropriate for the conditions on site? The surveying equipment used in marine site investigations is sensitive to vessel movement as the motion of the vessel adds noise to the dataset. In an exposed location such as the west coast of Ireland this can become a serious constraint.

Stage 2: The installation process. Are meteorological and hydrodynamic conditions on site suitable for the installation of a cable? Would it be possible to hold position on site during cable deployment?
Stage 3: Cable Operation. The safe and reliable long-term operation of the cable must also be considered. Would cable protection be sufficient against the hydrodynamic conditions in the estuary?

Stage 4: Monitoring. Finally, any long-term monitoring or maintenance of the installed cable protection measures must be considered, for example regular inspections may be necessary to ensure that the material used to protect the cable remains sufficiently robust and still *in situ*.

In order to identify the likely constraints for routing a cable across a harbour, estuary or from an offshore location, the first action is to gain an understanding of the site conditions. Initial investigations began with desk studies to define any widely known considerations for placing a cable in the estuary such as meteorology, wave and tidal current climate or known geology. Investigations at this stage included a review of shipping use and fishing traffic in the Shannon estuary, to establish the presence of any dumping areas of waste or munitions within the vicinity and to determine locations of any known facilities such as offshore installations, subsea structures or obstructions, existing pipelines and cables or coastal protection works.

Following the desk based study comprehensive site investigations were carried out. These began with determining the tidal current climate in the estuary, which was undertaken with an Acoustic Doppler Current Profiler (ADCP). A detailed bathymetry of the seabed was established through surveys with multibeam systems. This was supplemented by mapping features of the seabed with side-scan sonar systems in order to identify likely areas of rock outcrops or sand waves indicating potentially mobile sediment systems.

Information on the geological profile of the near-surface geology was established through a 'pinger' geophysical investigation and supplemented by an intrusive investigation. Vibrocorers were used to recover up to 6 metres of sample from sites across the proposed route. These were used to identify geotechnical properties of the sediments, any contamination and thermal resistivity of the material. Finally, measurements of the magnetic field on the seabed were established using a magnetometer. This is a useful tool to identify any archaeological features either lying on the seabed or buried close to the surface.

Statutory requirements for undertaking the investigation

In Ireland, the area of land between the foreshore and 12 miles offshore is owned by the State and as such any investigations or works undertaken on this state-owned land require permission from the Government in the form of a Foreshore Licence (details of which are set out in Section 3 of the Foreshore Act, 1933). Accordingly a Foreshore Licence was applied for and obtained. The licensing authority for Foreshore Licences at the time of this project was the Department of Communications, Energy and Natural Resources (DCENR), this responsibility has subsequently been transferred to the Department of Agriculture, Fisheries and Food. It was a requirement of the Foreshore Licence that an archaeologist should oversee the works and that due consideration should be made for the dolphins in the Shannon estuary.

The estuary has been nominated as a candidate SAC (Special Area of Conservation) under the EU Habitats Directive for the bottle-nosed dolphin population (Berrow 2000). Bottle-nosed dolphins use sound as both a communication and navigation tool and can suffer adverse effects from the frequencies of sound waves used in marine investigations (Leeney 2007). It was therefore a requirement of the Foreshore Licence to have a Marine Mammal Observer on board at all times during the investigation.

Use of the magnetometer in the detection of any surface or subsurface sites of archaeological interest along the likely cable route was also a requirement of the Foreshore Licence. The results of the magnetometer survey and the side-scan sonar survey were later provided for analysis by a suitably qualified archaeologist who had been approved by the Department of the Environment, Heritage & Local Government.

Investigation difficulties

A number of difficulties are likely to be encountered whilst surveying in an exposed environment such as the Shannon estuary. Much of the passive equipment used could only function in relatively calm conditions. This required regular and careful monitoring of the weather forecast and close coordination between EirGrid, Mott MacDonald Pettit and the Contractor, Pelorus Surveys to ensure the project team mobilised into workable weather conditions.

Initially it was planned that the survey lines would run shore-normal from north to south as this was the direction that the cables would run. Once the survey began, however, it quickly became apparent that it would be necessary to run the investigation with shore-parallel surveying lines, owing to the strong tidal currents making it difficult to run the vessel across the estuary in straight lines following the proposed cable route. This required the collection and processing of additional data but ensured full coverage to provide the data required for the study.

When undertaking a cable route study it is also preferable to use a diving survey to allow direct observation of ground conditions at the seabed. During the desk study, however, it was established that the tidal currents across the estuary were too strong for diving and visibility was very poor, therefore no direct observation of the seabed was undertaken for the site investigation, though it may be necessary in due course for divers to undertake archaeological investigations at the landfalls.

Weather conditions imposed further constraints due to the danger of operating the lifting equipment required for the vibrocoring survey in high winds or in significant swell. Inevitably these conditions will also have future implications for cable installation methodology and future cable repairs if required.

Survey results

Results from the ADCP current profiling investigation in the Shannon estuary showed that tidal currents of up to 6 knots are common during spring tides in ebb flow, 4.5 hours after high water. These currents were significantly higher than indicated on the Admiralty Charts.

Additionally the ADCP survey results demonstrated that there are reverse eddies towards the landfalls at the site. As the tide flows through the estuary and around headlands, eddies often form in the lee of headlands (Figure 1). The formation of these eddies, coupled with up to 6 knots of tidal flow had an impact on holding the position of the vibrocoring vessel over the required sampling site to obtain cores of sediment. Such conditions will later bear significance on the time and equipment required to place the cable.

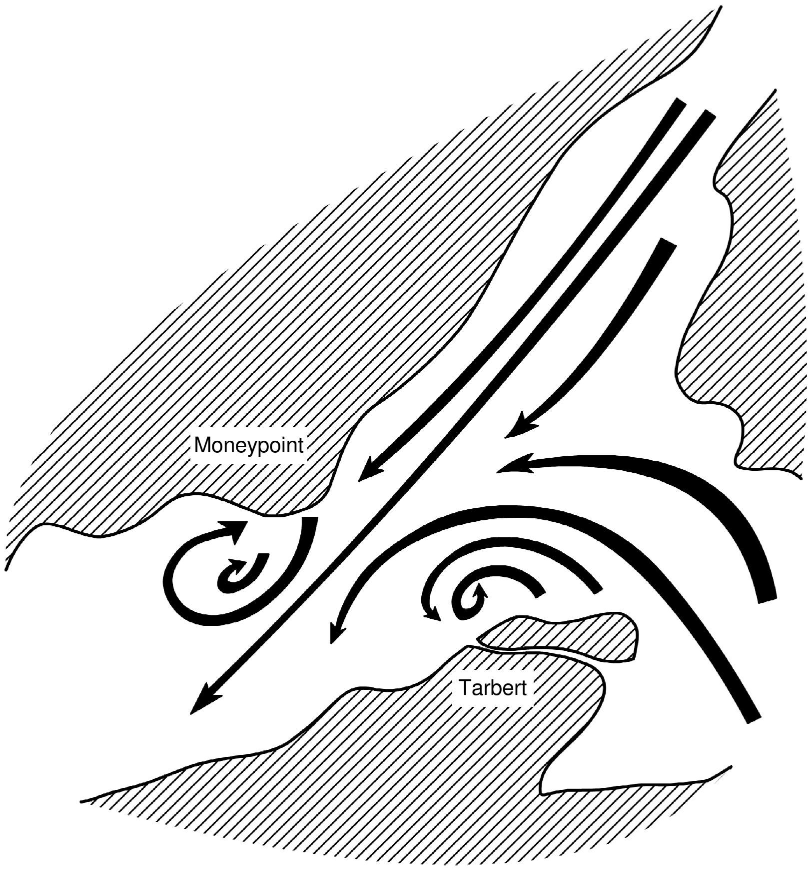
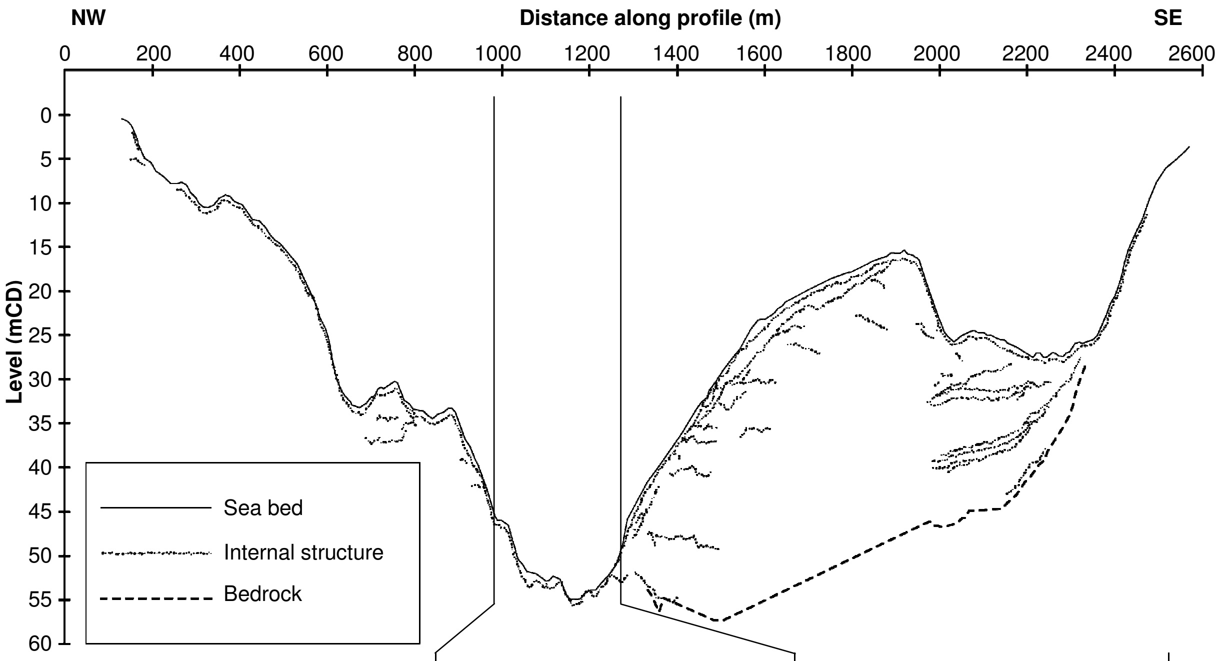


Figure 1: A 2-D illustration of eddies forming around the headlands of the Shannon estuary on the ebb tide

The multibeam survey revealed a complicated bathymetry across the Shannon estuary with water depths exceeding 60 metres in the centre of the channel across some transects, the survey also highlighted the steep side slopes to the north of the channel.

Collating a ground model

Once combined, the results from the side scan sonar 'view' of the seabed, the geophysical illustration of the first few metres of subsurface geology and the geotechnical results from the vibrocoring survey can be collated to form a geological ground model. A three dimensional understanding of the model was built up through multiple crossings of the channel. A simplified illustration and description of a cross-section through the ground model is shown in Figure 2.



Ground Conditions 0-950m:

Geophysics
No bedrock identified, bedrock may be too deep or obscured by overlying deposits

Side Scan Sonar
Shows high reflectivity indicating cobbles or exposed rock

Intrusive Investigation
Poor recovery in this area.
Mud recovered for 0.5m
Indicative of cobbles > 86mm

Ground Conditions 950-1250m:

Geophysics
0-1m of superficials in the central channel

Side Scan Sonar
Indicates fine to medium grained sediments
Sand / gravel

Intrusive Investigation
Not available for central channel

Ground Conditions 1250-2600m:

Geophysics
Shows superficials thickening whilst bedrock remains at depth

Side Scan Sonar
Shows sand/gravel with sand waves.
The wave lengths vary from 5-20m

Intrusive Investigation
Full 6m recovery from the vibrocore indicating loose material

Figure 2 - A summary cross-section of the ground model including bathymetry, side scan sonar, geophysics and vibrocoring results

The four key implications of the survey results for cable installation are:

1. The preferred methodology for cable installation and protection is water jet trenching and burial of the cable within *in situ* superficial sediments. There is little superficial sediment (between 0-1m) in the deepest part of the channel. This is often the case in high-energy, tidal nearshore locations, where high current speeds may prevent superficial sediments from settling at the site.

2. The northern side of the channel is composed of boulder clay. This material contains boulder or cobble sized particles set in a clay, sand and gravel matrix (such as that observed in Dublin by Long and Menkiti 2007). It is not possible to quantify the

particle sizes within this matrix, as only a small amount of sediment was obtained during the vibrocoring study. This can be attributed to the nature of the vibrocorer, which has a narrow aperture of 86mm to collect a core of sediment. If the sediment contains any particles greater than 86mm in diameter, these are not collected by the corer and prevent deeper sampling at that site. This sediment will provide a considerable challenge for cable installation as the larger particles may form obstructions to excavation of the required 1.5m deep trench.

3. The sides of the channel are relatively steep – in places the angle of repose of the boulder clay on the northern bank reaches up to 17º.

4. The southern bank of the survey area is characterised by sand waves of between 5 and 20m in wavelength. This indicates that superficial sediments are present but it also suggests that the sediments are potentially mobile which will certainly have implications for the installation methodology and cable protection.

A suite of geotechnical, contamination and electrical tests of the soils retrieved through the vibrocoring survey was undertaken. The geotechnical tests were used alongside the other information to build the ground model of the site and to determine a suitable approach to burying the cable. The contamination tests were used to establish whether any pollutants had been accumulated into the soils that may subsequently be re-suspended during the cable installation process. The thermal resistivity of the soils (i.e. a measure of their capacity to conduct heat away from the cable) was also tested in the laboratory to identify to what degree the superficial sediments present could affect the temperature of the cable.

Results derived from the magnetometer did not provide the archaeologists with any positive identification of significant features. However, upon examining the side scan sonar data the archaeological team postulated that there may be the remains of a rowing boat called a *Currach* lying on the seabed across one of the proposed routes. Principally Irish, the *Currach* was a fishing and transport vessel composed of a wooden frame over which animal skins or hides were stretched. The possible *Currach* was identified early on in the surveying period and a 100m exclusion zone was set up around the site for the vibrocoring survey to prevent any damage to the potentially important site during the intrusive ground investigation stage. This exclusion zone will also apply to the cable laying stage.

The influence of scour on potential cable installation options

Power, telecommunications cables or pipelines laid in the offshore environment have often been placed or fixed on top of the seabed and not trenched into sediments (Jinsi 1982). This methodology for placing cables on the seabed has been proven as an effective method of placement in the offshore environment. In the more hydrodynamically active nearshore environment, however, exposed cables on the seabed would be subject to strong scouring forces.

When currents flow over a cable or pipeline that may have been placed on top of sediments or suspended above the seabed, eddies will form in the lee wake of the structure. These eddies result in a periodic fluctuation in the bed shear stress in the lee wake of the cable (Figure 3). This fluctuating shear stress enhances the potential for scour (Mao 1986). The pressure gradient across the soil element under the pipe forms as positive pressure. This acts on the sediments supporting the cable upstream, while the sediments downstream of the cable are sheltered from this pressure by the cable itself (Figure 3). This pressure gradient is an important factor in initiating scour underneath the cable (Whitehouse 1998, Liang and Cheng

2008). Once a sufficiently strong seepage flow occurs underneath the pipe then a sudden and localised removal of bed material by piping occurs, aided by the excavating forces (Figure 3). When water starts to pass through the confined space under the cable, scour occurs rapidly and can lead to the formation of wide scour pits (Whitehouse 1998).

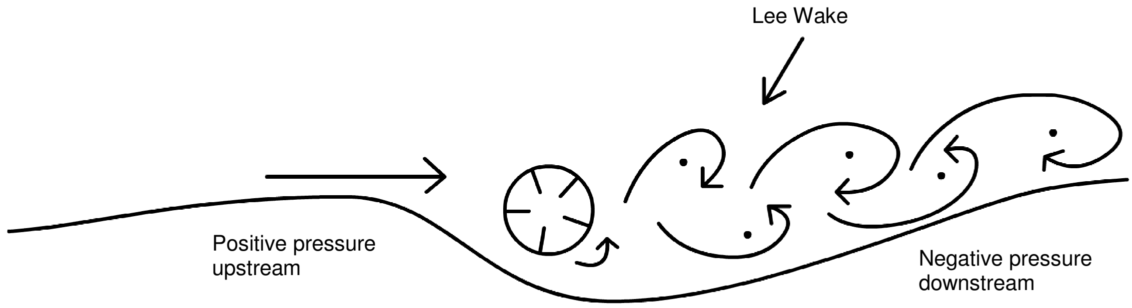


Figure 3 - An illustration of flow-cable interaction in unidirectional flow. After Whitehouse (1998) and Liang and Cheng (2008).

In the nearshore environment, an exposed cable may become unexpectedly suspended due to the loss of bearing sediment and is thus subject to hydrodynamic loads (Jiao 1991). Once uncovered and suspended, the cable is exposed to other dangers imposed by the operations of other underwater objects such as anchors and fishing trawls (Liang and Cheng 2008), which is particularly relevant in a busy shipping channel such as the Shannon estuary.

Within a tidally influenced estuary, the tide will turn every 6 hours causing currents to flow in the opposite direction, thus the scouring forces at work also reverse direction. Under the high-speed tidal current conditions of the Shannon estuary, it was decided that the cable must be securely buried to avoid subjecting it to such forces. As a result, three potential installation methodologies for the cable were considered for the Shannon project:

1. The preferred cable installation methodology was initially to either excavate or jet a trench to place the cable within superficial sediments. This would be followed by backfilling the trench or potentially allowing natural sedimentation processes to bury the cable. In the Shannon example, however, it is clear that where sediments do exist, they are either difficult to trench within (i.e. the boulder clay on the northern bank with unknown larger particle sizes) or potentially mobile (i.e. the sand waves on the southern bank).

2. Another option was the installation of the cable in a 3 to 4m internal diameter tunnel from one side of the estuary to the other. This would be excavated using a tunnel boring machine (TBM) approximately 20m under the sea bed. Initial geological assessments of the exposed rock at the landfalls implied that the subsea bedrock would be heavily faulted, which was later confirmed by the geophysical survey. Using a TBM is a costly process and the difficulties of supporting a tunnel in heavily faulted rock whilst digging with a TBM are well documented (Barton 2000) and would need careful consideration.

3. The final cable installation methodology considered involves placing the cable into position directly on the top of the seabed. Rock armour would then be placed over the cable to hold it in position and to protect it from meteo-oceanic and hydrodynamic conditions at the site. This method would also protect the cable from being disturbed

by passing ships dragging anchors etc. This is not an ideal solution as the cable itself needs to be well protected to withstand the rock placement process and there may be a number of difficulties with this methodology, including the accuracy of the placement of rock at up to 60m depth under difficult tidal conditions. In addition, such installations are a noisy process and have the potential to disturb the dolphins of the Shannon estuary. By burying the cable in rock we would effectively be creating a small submerged breakwater, which will need to be monitored and maintained as necessary. This is due to the effects of scour as the rock units will be subject to the processes discussed above and could settle unevenly (Jinsi 1995).

Conclusions

It is essential to gain a detailed understanding of the characteristics of a nearshore site prior to the selection of a cable route. This detailed understanding of the geological materials present and the hydrodynamic forces at work across the route is key to identifying the most feasible cable installation option providing greater assurance of project delivery, success and longevity.

Although each nearshore site has different characteristics, the example study from the Shannon estuary has captured a number of the most challenging site conditions including varying drift geology and a difficult hydrodynamic setting. The discussion of the Shannon Crossing Feasibility Study has highlighted at least six key risks to the installation and operation of the cable, most of which may be encountered by other cable placement operations in the nearshore environment. The six key difficulties are:

- Trenchability of the soils - the northern bank of the estuary is composed of overconsolidated boulder clay which is likely to prove a difficult material to trench into and has a number of unknowns associated with particle size. The clay is, by nature, cohesive and holds together the larger particles in a matrix. Key concerns, however, relate to whether it is possible to trench through a matrix containing unknown boulder-sized particles.

- Limited superficial sediment availability - there are limited superficial sediments available in the centre of the channel for cable trenching. As discussed, this is not unusual in the nearshore high-energy environment and may prove a key constraint to a number of nearshore cable routes for marine renewable energy installations.

- Mobile sediments - the southern bank of the estuary is composed of sand and gravel and is characterised by sand waves, indicative of actively mobile sediment. Mobile sediments are a common feature of the nearshore environment and if the cable is to be trenched into potentially mobile sediments a thorough assessment of the rate of sediment movement must be undertaken to consider the potential risk of cable exposure.

- Hydrodynamic challenges - the complex eddies and fast flowing current regime within the estuary will make it difficult to place a cable with precision at depth and more challenging to install rock protection on top of the cable. Such hydrodynamic challenges are likely to prove a constraint for any nearshore cable route but this may prove particularly challenging for sites selected for returning marine derived renewable energy to shore.

- Ecological factors - in this example, the presence of a protected species, the bottlenose dolphin, constrained the use of sonar-based equipment during the investigation. The sensitivity of these creatures may have a subsequent effect on the type of cable installation and protection measures used. The nearshore environment is often characterised by an abundance of ecological diversity, far more than in the open ocean. As a consequence, ecological constraints may prove a more critical issue in the case of nearshore cable installations than has previously been encountered with open ocean telecommunication cable installation or oil and gas pipeline installation.

- Archaeological factors - the coastal environment worldwide has historically been a highly populated area and inevitably, remnants of the past will have been left behind. In the Shannon example, the possible discovery of a *Currach* meant that an exclusion zone was set out, establishing an area which could not be used for cable placement.

During the survey in Shannon five different crossing configurations were considered, however, each route exhibited similar site complications to a varying degree, preventing the possibility of routing around obstructions, steep slopes or areas of potential sediment movement.

It has been demonstrated throughout this paper that the installation of nearshore cables is beset with a number of hydrodynamic, geological, ecological and archaeological difficulties. The Shannon estuary cable crossing was chosen as an exemplary case due to the sheer volume and diversity of the challenges exhibited throughout the study. These issues highlight a broad range of constraints, many of which could apply to any location where a cable is to be installed in the nearshore environment.

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