# Cable Protection Systems and Submarine Cable Failures

## Typical causes and remedies

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# Document Notes

## Executive Summary

According to 4Coffshore, around 4,600 subsea cables have now been laid and are serving offshore wind farms globally. Of the 4,600 around 10 incidents are declared annually, resulting in an average cable downtime of 100 days. In the past 7 years 90 subsea cable failures occurred totalling over EUR 350 million in insurance claims.

This is alarming for an offshore renewables industry in rapid expansion seeing many new developments across the globe. The challenges for the submarine cable connections are primarily driven by the environmental loads which cables are expected to withstand and the increasingly larger offshore installations, often featuring hundreds of connections, increasing the overall probability of failure. The failure mechanisms are mostly well documented experimentally and the physics behind is well understood, however not always applied correctly. Numerical modelling developed on these principles allow to determine the risks for these failures to occur, supporting the evaluation and comparison of several remedial actions to reduce risks. This paper provides an introduction to the global failure mechanism associated with cable protection systems (CPS), outlining the methodologies that can be employed to assess and prevent submarine cable failures with specific emphasis across the transition section from the seabed to the offshore WTG foundation structure where most of the documented failures occur.

**Riccardo Felici**
Senior Cable Consultant/Country Manager, Vietnam – OWC

**riccardo.felici@owcltd.com**

**Daniele Caruso**
Head of Cable Department/Country Manager, Italy – OWC

**daniele.caruso@owcltd.com**

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# 1. Introduction

With the expansion of offshore wind deployment around the world, the industry is witnessing an unprecedented rise in submarine cable installations. When considering the largest bottom fixed offshore wind farms currently operating, these will have more than 80 wind turbines installed. For each of these turbines there would typically be up two cable connections each, making for some 160 inter-array cables connections.

It is comprehensible that for the same percentage of failure on cables these are now accounted for a much larger number of losses. Furthermore, the cables, even within the same development field, are now exposed to a much larger variety of environments with different current forces and even wave distributions.

All these factors combined with typical and well understood mechanics of failure lead to an increased number of incidents which the industry is facing as a whole.

Longitude Engineering, and the wider ABL Group, are at the forefront of the industry having collaborated with several companies in the industry for the past 10+ years to prevent these failures through analysis and mitigating measures.

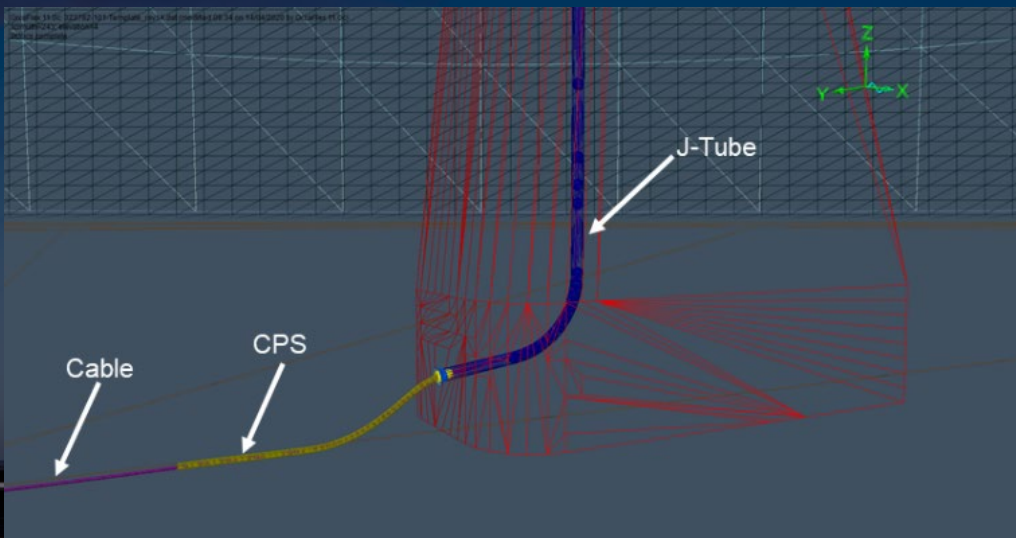



Figure 1 - Example numerical model for analysis

Through recent developments with major developers in the offshore wind sector, there is now an interest in further understanding the root causes, finding ways to solve failures and preventing them from occurring in the first place.

This paper is intended to provide a general understanding of the phenomena that can lead to failures and how can they be analysed to allow risk mitigation and loss prevention.

# 2. Submarine Cables in Offshore Wind

Submarine cables are amongst the key components of any offshore wind installation as they allow for the transmission of electricity between the turbines to the substation and eventually to shore.

Failures occur either during installation, caused by accidental damage, or due to fatigue and/or maximum strength limits being exceeded during operations. This paper will focus mainly on the latter failure modes. It is however also critical that the installations risks are well evaluated and understood to mitigate the overall risk of failure.

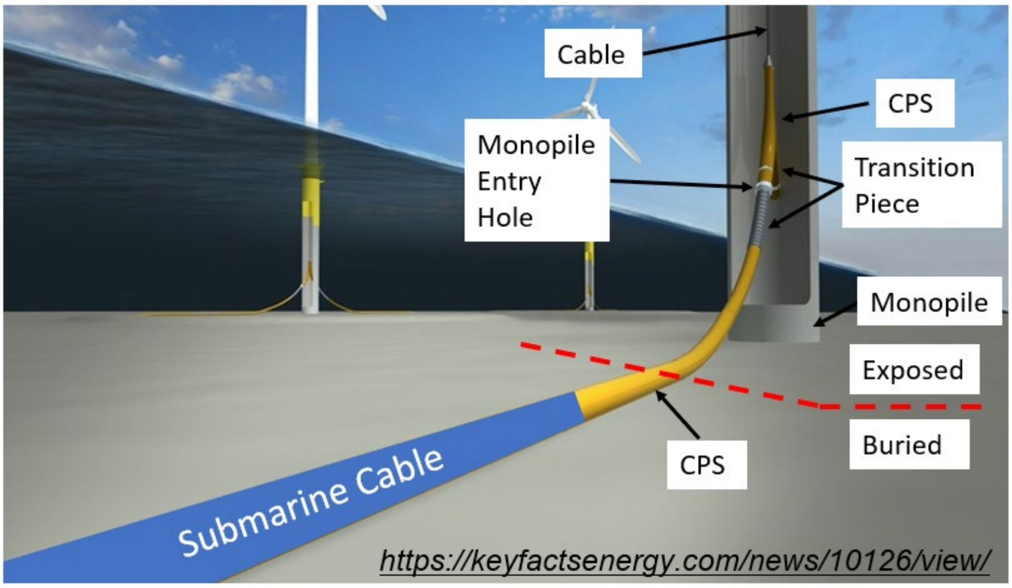



Figure 2 - Typical section view of cable components at Monopile installations

As the cables approached the foundations of a Wind Turbine Generator (WTG), whether a jacket or monopile foundation, there is an exposed section in which the cable will need to be unburied elevate to the J-Tube or Entry Hole and subsequently reach the jointing area.

This exposed area is one where there are several phenomena, both hydrodynamics and geophysical, that come into play and have a direct impact on the cable's dynamic behaviour. To withstand these dynamic forces a Cable Protection System (CPS) and scour protection are installed in this area to withstand the hydrodynamic forces and the consequent scouring respectively.

# 3. Cable Protection Systems

As anticipated in the previous section, CPS are used to protect the exposed section of cable between the interface with the foundation and the burial point against various factors that negatively impact on the cable lifetime. This exposed area is in fact subjected to increased dynamic forces, which the (static) cable is not necessarily designed to survive over the lifetime of the installation.

A CPS generally consists of three sections, a Centraliser or Monopile interface, a protection system for the dynamic area, and a protection system for the static area.

There are several different design in the industry but typically the CPS is made of different sections, combining bend stiffeners and bend restrictors.

Bend stiffeners are conically shaped polymer mouldings designed to add local stiffness to the product contained within, limiting bending stresses and curvature to acceptable levels. They are typically used in proximity of the foundation interface.

Bend restrictors comprises of a number of interlocking elements that form a semi-rigid curved structure, engineered to inhibit bending beyond a designated minimum bending radius (MBR) at a specified design load in static and quasi-dynamic applications. Different material can be used, including cast iron and polymer.

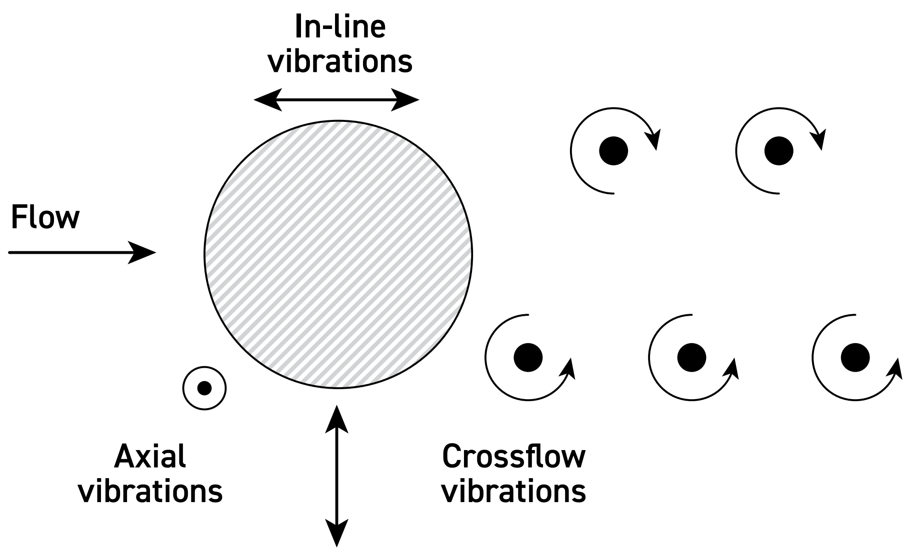
These systems need to be designed in such a way that they can be easily installed and at the same time able to protect the cable for its entire design life.

# 4. Hydrodynamic Phenomena

The exposed section of cable, covered by the CPS, will be subject to current and wave forces. These forces will act in the worst case perpendicular to the cable lay direction meaning that the largest area is then exposed to the flow.

These forces will typically be weaker in the deeper sites (Water depth > 25m) while being considerable in shallower sites. Considerations for each site, including the monopile or jacket design and the local environment, will then dictate where the effect of these forces are such to be a threat to the CPS' and cable's integrity.

Knowing that an installation would have an expected lifetime of 15-20 years, it will then need to be able to withstand the typical weather and also any large storms that might be seen through its lifetime.




Experimental and Numerical Studies of Vortex Induced Vibration on Cylinder

**Figure 3 - Flow disturbances**

Another main phenomenon is then the impact of large structures and the CPS free span itself on the water flow. It is known that when a cylindrical body is placed on a steady flow, it will start to generate a series of vortices on its trailing end only at critical Reynolds Numbers (Re).

These vortices contribute to a local disturbance of the flow downstream which has several impacts on both the cable and soil near the monopile or jacket.

# 5. Scour Formation and Development

With regard to the soil, the locally disturbed flow will start to induce the soil particles to be moved further downstream. This effective movement of soil over the period of years will induce the formation of a scour hole or pit. Depending on the soil type, water depth, environment and foundation type, this scour pit will present different depth, length and width.

The scour formation subsequently leads to a longer section of CPS being exposed which in turn increases the forces generated on the cable and CPS system.

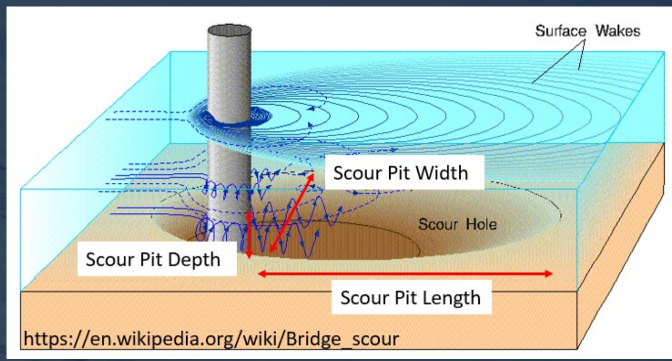



Figure 4 - Scour Pit

# 6. Failure Modes

When calculating the forces acting on the CPS and cable during the nominal current conditions and during the 100-year return storm (considered in the analysis), it is possible to note a pattern of failure modes.

The weak-link is typically at the interface of two different systems. This is typically in three areas along the cable:

- At the CPS to Monopile/J-tube interface, where the largest bending moment is expected;
- At the interface between sections made of different material (e.g. interface between bend stiffener and bend restrictor) where a stress concentration might occur.

These same failures are also noticed in several reports from site investigations after cable failure.

# 7. Pre-emptive Measures

The best way to solve the problem is to have a detailed system assessment throughout the stages of the project development where different steps may be taken to pre-empt failure.

The first solution, that can only be implemented at early development stages, is an accurate met-ocean analysis of the current and wave conditions along with a geotechnical analysis based on this data. Current and waves will have prevailing directions that determine the main loading on the system and main scour direction. Depending on the scour and expected cable load, it is possible to optimise the cable connection orientation or height above the seabed.

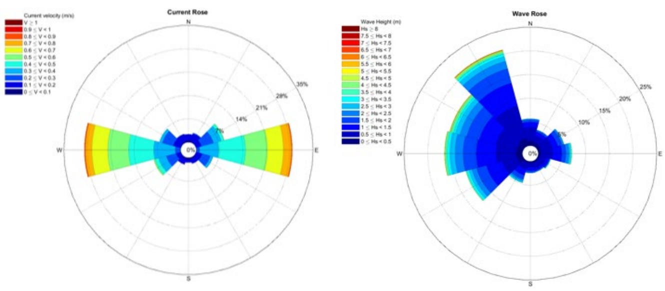



Figure 5 - Site specific Met-Ocean analysis

At later stages of development during detailed design, it is then possible to change the following:

- Scour protection profile - if any;
- CPS length;
- CPS properties – such as stiffness;
- Burial profile (grade out point, etc.)
- CPS constraining through mattresses / rock berm on top of scour protection – extreme cases;

The benefit and disadvantages for these different solutions can only be evaluated when analysing  the entire wind farm. Longitude has developed a clustering technique to group similar loading and environmental conditions for a wide field.

Soil data along with the other main system' inputs are processed by a software developed in-house. Subsequently several global Orcaflex simulations are run and post-processed to assess the improvements achieved using a range of different variables.

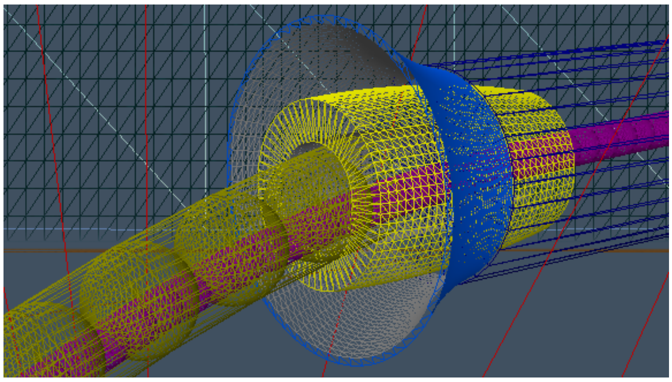


Figure 6 - Global Orcaflex model connection view

Typical analysis would be Global Ultimate Limit State (ULS), Global and Local Fatigue Limit State (FLS) and Vortex Induced Vibrations (VIVs) Assessment.

With regards to CPS Fatigue, it is strongly recommended to carry out a local analysis by developing an FEA model of the CPS and calculating stress concentration as a function of global loads (tension range and bending moment). In this way, by combining the results of the Global FLS and the local FEA analysis, it is possible to asses more accurately the potential fatigue damage of the system and identify critical areas that might need a design optimisation.

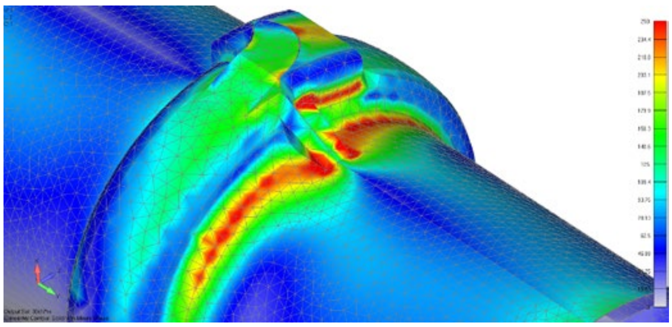


Figure 7 - Example of FEA analysis

Through these analyses, it is possible to better understand the local behaviour of the system and ensure the cable and CPS will be able to withstand the combined loads throughout the design life.

# 8. Corrective measures

Following a cable failure or through routine maintenance surveys, there is a range of potential corrective actions to be made.

It is always possible to reassess through analysis the acceptable degree of scour, or any development observed during a site survey and determine whether there is an immediate need for a remedial intervention.

In case the failure may be imminent, solutions aimed at stabilising the CPS, such as sand/rock bags, concrete mattresses or rock placement may be deployed although costly.

When a critical failure has already occurred, it is always recommended to carry out a detailed analytical investigation on the root cause and not simply replace like for like. Especially when installing a new cable in monopile foundations where a higher entry hole is used, the CPS will have a larger free span and higher loading making it critical to be reassessed to avoid further failures.

# 9. Contracting issues

One last root cause identified, though in cases hard to pin-point, following years of installation is due to contractual obligations that may not result in the right solutions, ie give problems down the road. Due to the nature of these faults these are often not discussed and harder to track.

It goes without saying that remedial actions and mitigations have to be made with the most complete understanding of the cable environment or made with data sets that are reliable. It is possible that mitigations can make matters worse, if they are rushed or made based on blunt contractual obligations, usually in the heated environment of the construction phase.

For instance, it was observed poorly designed rock berms added, following unreliable Depth of Burial data; sometimes when an 'as-built' was created by poorly calibrated plough data or 'ploughed' data made worse by a binary approach to contract obligations instead of re-assessing the burial risk as it stands versus the risk of a mitigation, especially if some of the available data is ambiguous. When a cable design decision is pressured contractual arrangements, there is often room for poor decisions.

To solve these issues a more nuanced approach is required during the construction, the right technical authority in a project looking beyond contractual obligations which can often be a blunt tool, is needed to ensure solutions are not rushed and that the technical and environmental criteria of the cable are not overlooked.

# 10. Loss and Insurance

After a decade of softening market for the insurance of Offshore Wind Farm (OWF) characterized by depressed pricing and broad covers and leading to sub-class results being poor and unsustainable for insurers, clients are now facing a hardening market with tightening of terms and conditions, limitations of cover, shrinking capacity for challenging placements and increasing rates.

One of the main drivers of the poor results of the OWF insurance sector and the subsequent market hardening was the high frequency and increasing severity of claims related to cable failure which still represents today approximately 75% of the total insurance claims paid by insurers. The majority of cable failures were historically found to be related to problems during manufacturing, transportation or installation, cable design and/or external damages.

As discussed in the previous paragraphs, cable failures due to environmental loads are expected to increase due to the growing number of operational OWF and their increasing time in operation if pre-emptive measures are not developed to minimize failures and no corrective actions are taken on existing wind farms. For new projects, the focus should be on pre-emptive measures as their costs are several orders of magnitude lower than corrective actions that could be running into the tens of millions for a single wind farm as lately indicated by industry professionals. CPS failures will potentially be further exacerbated with the development of Floating Offshore Wind Farm due to the increase complexity of the cable dynamic behaviour.

With the number of new OWF projects and operational covers coming on line increasing at a fast pace, the insurance industry will have an essential role to support this growth but insurers will not underwrite risks unless it is commercially acceptable and sustainable.

Early engagements and discussion are essential to achieve cost effective and fit for purpose insurance placements benefiting all parties involved. Insurance buyers will need to demonstrate, at all stage of the OWF life cycle being design, construction and operation, strong engagement and robust Risk Management, Process and Control. In addition to this, it has become clear from the studies of past incidents that one size does not fit for all and that detailed analysis and modelling are required to understand cable behaviour at local level and optimize cable protection system to minimize future failures. We expect insurers to put additional emphasis on project modelling, validations and certifications to mitigate the risks associated with the OFW placements, with a special focus on cables.

# 11. Discussion & Conclusions

Array Cable failures in offshore wind farms are increasing. More specifically, CPS and cable/scour protection interaction failures over the last years have been the subject of discussions within the Offshore Renewable Industry aimed to provide robust mitigations against reoccurrence. Array cables and associated protection systems On-bottom stability has become a key element to address for future developments.

A Numerical modelling approach for design, installation and repair can provide essential insights in the systems and ensure that changes are made to avoid these failures.

A detailed knowledge of the local metocean conditions at an early stage of the project development is critical to drive the design approach by undertaking a “fit for purpose” solution tailored on the specific site requirements.

The Cable protection systems design need to account for this variability in local combined loads and develop a strong interface with developers aimed to provide a robust and risk assessed solution for the specific metocean environment where the project will operate.

This paper provided a technical overview of the failure modes mechanics and some mitigation measures aimed to reduce risks in existing systems and prevent failure occurence.

As a group involved in all the stages of a wind farm technical life, we recognise there are also, other areas of improvement which are key in mitigating the risks:

- **Repair Strategy**
  Although it’s best to avoid the failure, it is also critical to be aware of upcoming ones and be ready for them. A rigorous survey schedule supported by site data and metocean information can help to identify the issue during its early stages. Pre-emptive actions can also be made on the repair side by having spare cable lengths in strategic port locations and prepare procedures and analysis for typical vessels which may carry out the repair. This will allow to considerably reduce the downtime of the cable.
- **Contracting**
  In some cases contract clauses are written by contract experts which do not have an overview of the technical implications of a certain measure, e.g. burial depth. Technical overarching input is necessary throughout all stages of the project of course in different measures.
- **Loss Adjusting**
  Deep knowledge and understanding of the cable design, manufacturing, installation and in-situ behavior are essential for a fast and fair adjustments of OWF cable related claims. As claim quantum and complexity are expected to increase due to the development of larger windfarms and turbines and of Floating Offshore Windfarms, insurance buyers, insurers and brokers have a common interest in appointing subject experts on cable claims.

These areas encompass not only the design and installation and require an industry wide approach to solve.

Through cooperation in projects and input from technical leads during all the stages of the project cable losses can be decreased in Offshore Wind Farms.

**Any questions?**

If you are interested in speaking to OWC or Longitude about cable protection or cable failure issues, please contact:

**enquiries@owcltd.com**

**enquiries.general@abl-group.com**

**OWC**, an ABL Group company, is a specialised independent consultancy offering project development services, owner's engineering and technical due diligence to the offshore wind industry, developing and realising projects across the globe.

Since 2006, **Longitude Engineering**, an ABL Group company, has delivered specialist design and engineering services in the marine, offshore renewables, oil & gas, defence, and offshore infrastructure markets. Our independence, expertise and experience make us a natural choice for a wide range of design solutions across Asia Pacific, Europe and North America.


**REGIONAL HUB OFFICES**

**LONDON**
1st Floor, Northern & Shell Building
10 Lower Thames Street
London, EC3R 6EN
UK

**T** +44 20 7264 3250

**HOUSTON**
10613 W Sam Houston Pkwy N
Suite 400
Houston, Texas 77064
USA

**T** +1 713 688 5353

**DUBAI**
Office 608, SIT Tower
Dubai Silicon Oasis
PO Box 128078
Dubai, UAE

**T** +971 4 3793612

**SINGAPORE**
112 Robinson Road
#09-01
Singapore 068902

**T** +65 6224 9200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**owcltd.com** **longitude-engineering.com**