OFFSHORE WIND ACCELERATOR (OWA)

Sub-sea Inspection Competition

Competition Brief

In partnership with

Drafted By:

OWA Sub-sea Inspection Competition

The Carbon Trust's Offshore Wind Accelerator programme is pleased to present this competition in partnership with:

DONG energy, e.on, EnBW, innogy, ScottishPower Renewables, SSE, Statkraft, Statoil, Vattenfall, The Scottish Government

This competition and subsequent support programme has been launched to support the further development and demonstration of technologies that address key offshore wind sub-sea inspection challenges. It is targeted at technologies that are currently at TRL4-6 with an aim to reaching commercial demonstration by Summer 2018. The competition aims to provide a unique opportunity for technologies under development or currently deployed in other sectors to access the growing offshore wind operations market.

TECHNICAL CHALLENGES

The size, geometry and cost base of offshore wind turbines present a unique set of requirements for wind turbine sub-sea inspection.

Industrial engagement identified the following inspection areas as the most critical and challenging for the offshore wind industry.

SUB-SEA WELD INSPECTION

CHALLENGE 1
Detection of sub-sea monopile circumferential weld flaws, particularly cracking and pitting

CHALLENGE 2
Detection of sub-sea jacket nodal weld flaws, in particular cracking and pitting

SUB-SEA GROUT INSPECTION

CHALLENGE 3
Inspection of monopile-transition piece grout condition, including grout density and separation of grout from internal steel work

CHALLENGE 4
Sub-sea inspection of jacket-pile grout condition, including grout density and separation of grout from internal steel work

PRIZE

The winners will have access to the following:

1. Mentoring
Regular support and steering from nine leading offshore wind project owner / operators.

2. Demonstration
Access to an operational wind farm to demonstrate your technology in front of key end users.

3. Publicity support
Support with raising awareness of demonstration result and technology within the offshore wind sector.

TIMELINE

Competition opens:
13th July 2017

Application deadline:
13th October 2017

Winners announced:
w/c 6th November 2017

Technology demonstration programme:
Summer 2018

ELIGIBILITY

Any organisation from any sector or country with a technology currently at approximately TRL 4-6 that addresses any of the above challenges

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1. Competition background

The Carbon Trust's Offshore Wind Accelerator is pleased to present this competition to identify and support new technologies for sub-sea inspection of offshore wind projects.

1.1 Competition Sponsors

The Carbon Trust

The Carbon Trust is an independent, expert partner of leading organisations around the world, helping them contribute to and benefit from a more sustainable future through carbon reduction, resource efficiency strategies and commercialising low carbon technologies. More information on the Carbon Trust can be found at www.carbontrust.com

Offshore Wind Accelerator

The Offshore Wind Accelerator (OWA) is a research and development programme focused on reducing the cost of offshore wind energy. To achieve this target, the OWA is aiming to develop cost-reducing innovations that can be implemented in existing and upcoming European offshore wind developments.

The OWA initiative is coordinated by The Carbon Trust and part-funded by the Scottish Government. The industrial partners are: DONG Energy, E.ON, EnBW, innogy, Scottish Power Renewables, SSE, Vattenfall, Statkraft, and Statoil.

More information on the Offshore Wind Accelerator can be found here:
https://www.carbontrust.com/client-services/programmes/offshore-wind

1.2 The need for a competition

The UK has had a world-leading offshore Oil & Gas (O&G) industry for several decades, and has successfully designed, built and operated numerous sub-sea structures in harsh environments. Sophisticated bespoke equipment including ROVs, saturated diving systems and a range of sensors have been developed for remote monitoring and maintenance, therefore it might appear that there is no need for new bespoke technology to service the offshore wind market – it should be a simple question of technology transfer.

However, in practice the offshore wind industry grew out of shallow water, nearshore/coastal marine civil engineering practice, not the O&G industry, and the structural designs that emerged are somewhat different from O&G structures, have different techno-economic drivers, and their maintenance has a very different cost base. A further, significant difference is the large number of separate structures in offshore wind, leading to the drive for repeatable solutions as opposed to fewer, more custom designs. This has led to some unique industry-specific challenges, for which new cost-effective bespoke techniques and equipment are needed. The two most significant issues to date are:

Grout failure, mostly in monopile/transition piece joints

> Designs and guidelines for offshore wind were developed from scratch, and the preferred approach in the UK was for a driven monopile (MP) with a Transition Piece (TP) grouted onto it as a spigot joint. Large diameter (~3.5 to 7.0 m) grouted joints, which transfer bending loads between two non-redundant primary structural elements in this manner, are unique to offshore wind. Problems with bond-cracking, grout crushing and tower slippage were encountered with the grouted joints on the early monopile turbine fleet. The design codes were revised following a Joint Industry Project in 2011/12 led by DNV, however many of the early fleet had to be repaired, and retrofitted with parallel load paths and structural monitoring systems. Inspection of the grout condition in these joints is therefore one of the areas of this call, and it is needed not only on the early designs, but also as a check on the performance of the new design of conical MP/TP joints that were proposed in the revised guidelines following the JIP. Technology for grout condition monitoring exists in the O&G industry, however the unique pile diameters, joint design,

component thicknesses, access constraints, frequency of monopile inspection, and the large number of monopiles installed, require bespoke development of solutions.

Looking to the future, more jacket structures are expected to be installed for offshore wind turbines, and when piled these structures require grouting in each of the legs. The current available techniques in the market mainly consist of a visual inspection of the accessible upper section of the grouted connection, but this gives very limited information to assess their integrity. Intrusive techniques such as coring can be used, but this is a destructive technique and a costly repair is necessary afterwards. Any issue that may happen during installation or later in operations cannot be adequately assessed without employing destructive testing and access is highly constrained.

Unexpected levels of corrosion in welds

Offshore wind foundations are subject to predominantly lateral loading, which is highly dynamic in nature. This gives rise to fatigue concerns in the critical primary members of both monopile and jacket structures. As with the grouted joints, experience in the early fleet has been that corrosion, especially inside monopiles, has been more severe than anticipated. J-tube seals have leaked and water has circulated up from the ground, leading in some cases to more highly oxygenated water contact with surfaces that were not painted or equipped with anodes. This has provided greater potential for pitting and weld defects, and leads to the second main area of the call, which is for the remote scanning and detection of weld flaws. The O&G industry has developed numerous ultrasonic, ACFM and magnetic scanning techniques for weld flaws – this call is for the transfer of such techniques, and development of bespoke equipment and processes, to account for the offshore wind-specific conditions. For example, access inside monopiles is a confined space and requires the airtight hatches to be opened and any gases vented. Similarly, diver deployment, especially in water depths >35 m where saturation techniques would be required, is expensive and limited by metocean conditions, whilst ROVs cannot always maintain the necessary probe contact pressure and scanning line.

Solutions developed for the offshore wind sector need to be realistically priced. The revenue from a single wind turbine is far less than that from an oil well, so any technology developed under this call must be cost-effective within offshore wind budgetary constraints. In addition, offshore wind foundations are built in their hundreds (maybe up to 150 for a single large farm), whilst O&G installations tend to be one-offs; any techniques and their deployment must be rapid, and the equipment easily transferable from foundation to foundation.

Opportunities for entering the sub-sea inspection market

As of January 2017, there are 3,589 turbines installed and grid-connected in European waters, making a cumulative total of 12,631 MW of generating capacity. Of these, the dominant design is monopiles (81% of substructures), followed by gravity foundations (7.5%), jackets (6.6%), tripods (3.2%) and tri-piles (1.9%). In the next ten years, this capacity is predicted almost to triple.

In terms of monopiles, it is estimated that around 35%-40% of the fleet (most of the pre-2012 structures) have potentially been affected by the grouted joint issue, and additionally some of the post-2012 fleet will require performance monitoring. We note that many new farms designs (ca. post-2015) have abandoned the grouted joint concept in favour of a bolted flange solution.

Some countries, such as Germany, require very onerous testing and approval processes for grouted connections that make the development of a suitable technique for inspection highly relevant.

Standards require that a sample of offshore wind sub-sea structures within each farm (typically 5-15%) be subjected to periodic inspection. This can be at varying intervals, depending on the standards used and the degree of "adaptive management" permitted in the Maintenance Schedule. Typically, intervals of 5 years (as per DNV standards) are adopted, or 4 years under BSH standards. If defects, or greater than expected corrosion, are observed then the inspection programme can call for wider (up to full farm, in the case of a serious generic problem) or more frequent inspections. If new techniques prove cost-effective, then they can become part of the periodic maintenance specification.

In light of the above, it can be seen that there is a potentially large ongoing market for offshore wind farm sub-sea inspection within Europe alone. Emerging markets in USA, Taiwan, Korea and Japan are likely to provide additional opportunities, especially for weld flaw detection.

The market entrance route for an OEM is likely to be one of two ways:

(i) Supply of equipment and training to established offshore wind inspection contractors.

(ii) Provision of full inspection service including equipment and trained personnel, contracting to the wind farm owner/operator/asset management organization.

1.3 Key competition aims

This competition aims to address the technical and commercial challenges by meeting the following objectives:

- To identify technology that can be developed or adapted to address the most significant challenges for sub-sea inspection of offshore wind farms;
- To support and steer technology with high potential through end-user engagement in the development process;
- To provide a platform to demonstrate technology to potential end-users.

2. Technical challenges

This competition looks to address four key challenges:

1. Sub-sea inspection of monopile circumferential welds;
2. Sub-sea inspection of jacket foundation complex node welds;
3. Sub-sea inspection of grouting between monopiles and transition pieces;
4. Sub-sea inspection of grouting between jacket foundations and piles.

More details on these challenges are provided in the challenge outline sheets below.

Detailed technology performance and operating requirements are outlined in Appendix 1.

CHALLENGE 1: SUB-SEA INSPECTION OF MONOPILE CIRCUMFERENTIAL WELDS

Background:

Sections of steel monopiles are circumferentially welded together with V butt welds. Unexpected levels of water ingress into the monopiles has led to significant issues with pitting and corrosion of the welds within the monopiles in early wind farms. Current technologies used for assessing weld flaws are slow and expensive, and cannot reach the resolution required in the challenging operating environment. In particular, innovation is required around automated deployment of any inspection technology.

The Challenge

OWA is looking to support the development of a technology that can detect surface flaws in circumferential butt welds of monopile cans, both inside and outside the monopile structure.

The inspection technology should be able to deliver a map of corrosion pitting and detect surface flaws of a minimum 5 mm. Monopiles are up to 8 m in diameter with a steel thickness of 40-150 mm.

Ideally this should be deployed through a remotely operated tracked vehicle, which must be able to operate in both the splash zone and fully submerged.

Reporting must include graphical defect maps that can easily be interpreted by a non-specialist.

More detailed specifications are outlined in Appendix 1.

Monopile during manufacturer, showing welds
Image: EEW SPC/Andreas Duerst Studio 301

What is currently done in the offshore wind sector

Currently, monopile welds are inspected by divers either through visual inspection or using hand-held ultrasonic or ACFM probes.

CHALLENGE 2: SUB-SEA INSPECTION OF JACKET FOUNDATION COMPLEX NODE WELDS

Background:

Jacket foundations are complex welded sub-sea structures constructed primarily from steel.

They are broadly similar structures to jackets deployed in the O&G sector.

Whilst there have not been significant issues with jacket welds to date, operators have concerns about integrity of welds over the lifetime of the project, and carry out regular inspections.

Current technologies used in offshore wind for assessing welds condition are slow and expensive and heavily reliant on the use of divers.

The Challenge:

OWA is looking to support the development of a technology that can detect surface flaws in circumferential girth welds or jacket nodes between the primary steelwork elements (e.g. legs, horizontal and vertical braces) and welds between primary and secondary steelwork elements (e.g. J-tube supports, boat landing fenders, etc.).

The inspection technology should be able to deliver a map of corrosion pitting and detect surface flaws of a minimum 5 mm. There is a wide range of member sizes varying from 0.4 m to 2.0 m diameter.

Ideally the inspection technology should be deployed through a remotely operated vehicle. Any inspection technology would ideally be able to operate in both the splash zone and fully submerged.

Reporting must include graphical defect maps that can easily be interpreted by a non-specialist.

More detailed specifications are outlined in Appendix 1

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Typical jacket foundation structure

Image couresy of Salzgitter Mannesman Renewables

What is currently done in the offshore wind sector

Currently, jacket welds are inspected by divers either through visual inspection or using hand held ultrasonic or ACFM probes. Occasionally ROVs are used, but such use is restricted by the jacket geometry.

CHALLENGE 3: INSPECTION OF GROUTING BETWEEN MONOPILES AND TRANSITION PIECES

Background:

The grout join for a monopile foundation sits between the transition piece and the foundation. It is typically formed of high-density concrete between two steel walls.

Grout joints have caused significant problems for wind farm operators and are of concern for most of the UK's early offshore wind monopile fleets. There are currently no means of accessing grout for visual inspection. Current methods for inspecting grout are slow, expensive and have significant health and safety-related issues. They can also be damaging to the structure.

The Challenge

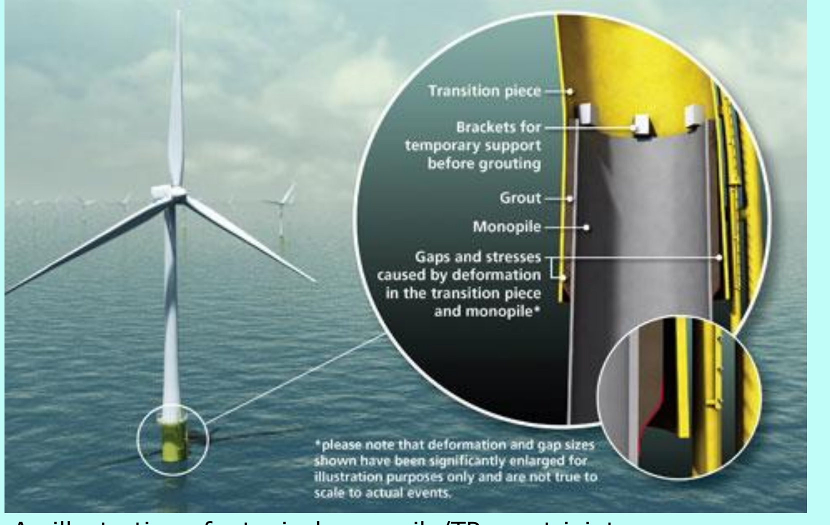
OWA is looking to support the development of a technology that can detect failures in the grouting between monopiles and transition pieces.

The inspection technology should be able to deliver a map of grout and steel thickness, grout density, voids and any cracking or fracturing. It should also be able to detect any separation of grout from internal steel surfaces and any ingress of water.

Monopiles are up to 8 m in diameter with a steel thickness of 40-150 mm and a grout annulus thickness of 20-150 mm. Any inspection technology deployed will need to operate in splash zone and sub-sea conditions.

Reporting must include graphical defect maps that can easily be interpreted by a non-specialist.

More detailed specifications are outlined in Appendix 1



An illustration of a typical monopile/TP grout joint
Image courtesy of DNV

What is currently done in the offshore wind sector

During inspections, visual inspection of the internal upper annulus and visual inspection of the outside of the joint are carried out. Sub-sea inspection is typically carried out using divers. When an issue arises, occasionally core sampling of the grout may be carried out.

CHALLENGE 4: SUB-SEA INSPECTION OF GROUTING IN JACKET PIN PILES

Background:

Offshore wind jackets are secured to the seabed with pin piles. There are two main arrangements in use; in the first, the jacket is lowered onto pre-driven piles, with the legs being guided inside the piles by stab/guidance plates. In the second, separate pile sleeves are welded to the jacket legs; the jacket is placed on the seabed and levelled. The pin piles are then inserted into the sleeves and driven to depth. In both arrangements, the annulus between the pile and the concentric steel member (either the internal pile or the external pile sleeve) is grouted to form the load path.

The integrity of the grouted joint is critical to the structure. German BSH standards can require specific monitoring of the grout integrity of jacket piles. The detection requirements are similar to those for grout monitoring in the MP/TP joint of monopiles.

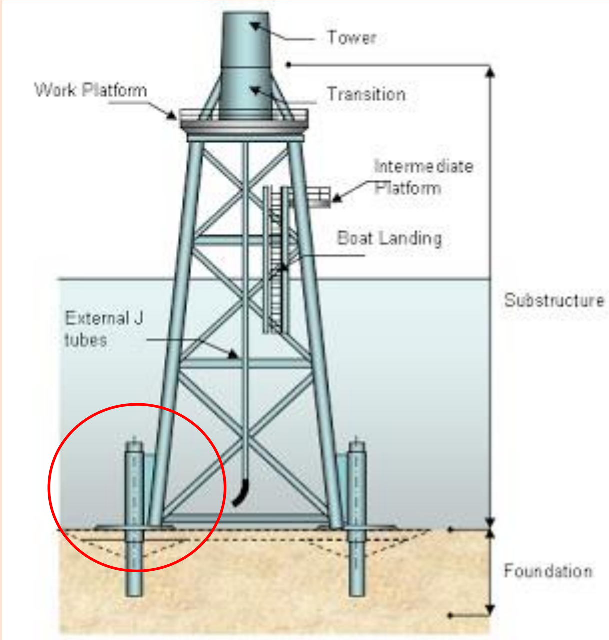
The Challenge:

OWA is looking to support the development of a technology that can detect failures in the grouting of jacket pin piles.

The inspection technology should be able to deliver a map of grout and steel thickness, grout density, voids and any cracking or fracturing.

Pin piles are approximately 1.5-2.5 m in diameter with a steel thickness of 30-80 mm. Any inspection technology deployed will need to operate in a fully submerged environment.

More detailed specifications are outlined in Appendix 1



Jacket pile interface; not pre-piled

Image courtesy of Garrad Hassan and Partners

What is currently done in the offshore wind sector

Visual Inspection of the accessible upper section of the grouted connection using divers. Occasional use of intrusive techniques such as sample coring.

3. Information for competition entrants

3.1 The prize

The selected organisations will be provided with access to the offshore wind sector and the key potential customers for their technology. Winners will have a unique opportunity to work with the Carbon Trust and nine key offshore wind owners to develop, demonstrate and publicise their technology. Support will be provided through mentoring, access to offshore wind sites for demonstration and support with publicity.

Figure 1. The prize – Support provided to further develop winning technologies

Winning technologies will be provided with the following support access to:

1. Mentoring by the OWA Foundations Technical Working Group (TWG)

- During the development phase, winning organisations will have regular access to the Foundations TWG, representing the key European offshore wind owners/operators. Winners will have the opportunity to attend bi-monthly meetings to raise questions, request data and get general steering to support the further development of their technology.
- Ad hoc support – Winners will be able to raise questions at any time with TWG members through mentoring by the TWG contact in the Carbon Trust.

2. Demonstration programme

Following the development phase, winning organisations will have access to an offshore wind farm in order to demonstrate their technology to the TWG.

- These wind farms will be located in Germany and the UK.
- The demonstration programme will be carried out during summer 2018.

The winning organisation will receive:

- Access to the wind farm
- Use of a crew transfer vessel on the sites
- Relevant site-specific training
- The opportunity to present findings to the TWG, consisting of the major potential customers for the technology

3. Publicity support

Assuming successful development and demonstration of the technology, the Carbon Trust will use its position and network to highlight supported technologies to the wider offshore wind community through social media, support with accessing events and general media.

It should be noted, for the demonstration element of the prize:

- Access to ROVs is not included (although access to ROV suppliers can be facilitated by the Carbon Trust if required)
- Additional qualifications/training are needed to access the wind farms, but will not be provided – these include:
  - GWO First Aid course
  - GWO Sea Survival
  - Medical Certificate – UKOOA or equivalent but not ENG1
  - GWO Manual Handling
  - GWO Fire Awareness
- The following additional qualifications may be required depending on access requirements:
  - Confined Space – Level 2 / Medium Risk (if working below the airtight deck in foundation)
  - GWO Working at Heights Certificate
  - EuP (electrically competent person) – Germany-specific
- Contractors should provide their own personal PPE, including survival suits

If any of these requirements are expected to be a barrier to entry to the competition, the Carbon Trust can support in finding a solution. Please apply and highlight where support would be required in this area. Whilst no direct funding is available through this competition, if accessing funds is likely to be a significant barrier to entry, the Carbon Trust can support organisations in accessing funding through third party funding schemes**.**

3.2 Competition Process

Application process

- Please complete the form outlined in Appendix 1 and ensure a complete summary of your proposed technology.
- Please provide an executive summary of not more than one page which provides a comprehensive overview of your proposed technology.
- All proposals will be primarily assessed based on the answers provided within these forms.
- The total application should not exceed 10 pages. Supplementary information can be provided as an attachment or URL link to a media file, but we do not guarantee to review all additional material.
- Your form should be submitted to Michael.Stephenson@CarbonTrust.com, no later than 17:00 UK time on 13th October 2017.
- A confirmation e-mail will inform you that your submission has been received.
- Applicants may enter more than one challenge. Each entry must be submitted on a separate application form.

Clarifications and enquiries

Any questions or requests for clarification should be sent to Michael.Stephenson@CarbonTrust.com by COB 1st September 2017. A response to the questions submitted will be issued on the tenders page of the Carbon Trust website (https://www.carbontrust.com/about-us/tenders) by COB 8th September 2017.

Competition timeline

The competition will open on 13th July 2017. The deadline for submission of entries is 17:00 UK time on 13th October 2017.

Any queries relating to the competition must be received by COB on 1st September 2017 and answers will be issued by the COB on 8th September.

Shortlisted Candidates will be invited for interview in the week commencing 30th October 2017.

Winners of the competition will be announced during the week commencing the 6th November 2017 with the demonstration opportunity becoming available in the summer of 2018.

3.3 Scoring Criteria

Submissions will be evaluated according to the following criteria:

Inspection capability	• Ability to detect the required flaws/damage • Ability to operate with given geometry • Ability to operate within operating and access conditions • Speed of inspection • System reliability	35%
Ease of deployment	• Level of automation • Speed of deployment • Need for specialist deployment equipment • Metocean constraints • H&S benefits • Cost effectiveness	35%
Delivery programme	• Technology readiness • Ability to deliver within timescales • Awareness of key development barriers and ability to address • Track record (organisation and technology)	30%

3.4 Eligibility

We welcome applicants from all industries in all countries. Entrants do not need to have any previous experience in offshore wind or a deep understanding of the offshore wind sector.

Development timeline

Technology must be ready for commercial demonstration by summer 2018. If this is unlikely to be the case, or if the technology is likely to be commercially available before this time, we would still encourage an organisation to apply; where this is the case, it should be noted in your application

3.5 IP and confidentiality

The Carbon Trust and OWA partners guarantee that all Intellectual Property (IP) included in submissions to the OWA Sub-sea Inspection Competition and all IP that will be developed during any subsequent phases is, and will remain, property of the provider. The information will be treated in confidence and exclusively for assessing and evaluation competition entry.

3.6 Funding support

It is recognised that companies will need to make some investment in order to further develop and demonstrate their sub-sea inspection technology for the offshore wind markets. Whilst no direct funding is available through this competition, the Carbon Trust and OWA would like to prevent this causing a barrier to entry to this competition. If required, support can be provided by the Carbon Trust to access funding from third parties.

If funding is likely to be required for your organisation to benefit from this competition, we would encourage your organisation to apply and note in your entry the level of funding likely to be required.

3.7 Additional information

Issuance of this invitation to submit a competition entry and subsequent receipt and evaluation of the proposals by the Carbon Trust does not commit the Carbon Trust to enter into a contract with competition entrants.

APPENDIX 1. DETAILED TECHNOLOGY PERFORMANCE AND OPERATING REQUIREMENTS

CHALLENGE 1: SUB-SEA INSPECTION OF MONOPILE CIRCUMFERENTIAL WELDS

Background:

Sections of steel monopiles are circumferentially welded together with V butt welds. Unexpected levels of water ingress into the monopiles has led to significant issues with pitting and corrosion of the welds within the monopiles in early wind farms. Current technologies used for assessing weld flaws are slow and expensive and cannot reach the resolution required in the challenging operating environment. In particular, innovation is required around automated deployment of any inspection technology.

Detection / reporting requirements:

- 5 mm surface flaws with 50% Probability of Detection
- Corrosion pits – map of area and depth
- Entrant to advise best achievable resolution and Probability of Detection for proposed equipment

Relevant geometry & materials

- Monopile diameter – 3.5 to 8.0 m diameter
- Steel thickness 40-150 mm
- Steel Grade – typically S355 (for monopiles & TPs)
- Weld/defect types:
  - Main welds of interest are the circumferential butt welds of the monopile cans.
  - Double-sided butt with weld cap width from 1/3 to 3/2 of wall thickness.
- Note that cans may have tapered thickness, typically 20-25%.
- Also there can be thickness steps at welds (typically below 10 mm), and;
- Adjacent cans can be misaligned arising from translation and ovality at manufacture (typically below 5% of wall thickness).

Operating conditions

- Equipment on the outside of the MP/TP must be capable of operating in both the splash zone (inter-tidal) and the fully submerged zone.
- Internal equipment must be capable of operating at the internal waterline and submerged in internal water (not freely circulating seawater).
- External currents up to 4 knots can be expected.
- Max water depth ~50 m.
- Internal conditions depend on the corrosion protection strategy inside the monopile. For older MPs (fully corroded surface and no water exchange), O_2 content will be depleted. Coating on welds, and corrosion protection systems will affect water chemistry (acidity).
- Internal underwater visibility may be poor.

Access constraints

- Access onto turbine platform is by Crew Transfer Vessel CTV); all staff must have relevant offshore tickets (requirements TBC by farm operator). Access depends on deployment method, and metocean capability of CTV, ROV and sensor deployment platform.
- Access inside monopile may require airtight lids to be opened; working inside is categorized as confined space, requiring appropriate safety procedures.
- Anode cages are mounted external to MP, which may impede access.

Other constraints/specifications

- Remotely operated tracked vehicle is ideally preferred deployment option.
- Note that surfaces may have paint coating applied (typically glass flake epoxy or high-build durability epoxy). Worst case could be 500 microns in the submerged zone region.
- Marine growth up to 100 mm can be expected, soft and hard, locally variable, and water-depth dependent. This may be largely removed prior to inspections if necessary
- Inside the monopile there may be J-tubes and cables and other monitoring instrumentation in-situ. Externally, there will also be J-tubes near the mudline (internal J-tubes), or J-tubes all the way up (if external J-tubes).
- Equipment must be capable of rapid deployment, easy control and preferably not require removal of marine growth.
- Reporting must include graphical defect maps that can easily be interpreted by a non-specialist.

CHALLENGE 2: SUB-SEA INSPECTION OF JACKET FOUNDATION COMPLEX NODE WELDS

Background:
Jacket foundations are complex welded sub-sea structures constructed primarily from steel. They are broadly similar structures to jackets deployed in the oil and gas sector. Whilst there have not been significant issues with jacket welds to date, operators have concerns about integrity of welds over the lifetime of the project, and carry out regular inspections. Current technologies used in offshore wind for assessing weld condition are slow and expensive and heavily reliant on the use of divers.

Detection / reporting requirements:

- Focus on girth welds
- 5 mm surface flaws with 50% PoD
- Corrosion pits – map of area and depth
- OEM to advise best achievable resolution and PoD for proposed equipment

Relevant geometry & materials

- Welds between primary steelwork elements, e.g. legs, horizontal and diagonal braces
- Welds between a primary and a secondary steelwork element, e.g. J-tube supports, boat landing fenders etc.
- Butt welds, double or single-sided
- Materials typically steel Grade S355, however may be higher grades
- Chord connections at elements can be 40 degrees up to 130 degrees
- Wide range of member sizes:
    - Legs – 1.0 to 2.0 m OD, 20 to 80 mm wall thickness
    - Braces – 0.4 to 0.8 m OD, 15 to 40 mm wall thickness
- There may be bevelling between adjacent cans of 1:5 if the thickness steps >3 mm
- Welds spaced a minimum of 300 mm
- Welds preps will typically be to EN 1011, quality requirements to ISO 3834

Operating conditions

- Equipment must be capable of operating in both the splash zone (inter-tidal) and the fully submerged zone.
- External currents up to 4 knots can be expected.
- Water depth up to ~50 m max
- Internal underwater visibility may be poor.

Access constraints

- Access may be restricted due to jacket geometry.

Other constraints/specifications

- Marine growth up to 100 mm can be expected, soft and hard, locally variable, and water-depth dependent. This may be largely removed prior to inspections if necessary.
- Equipment must be capable of rapid deployment, easy control and preferably not require removal of marine growth.
- Reporting must include graphical defect maps that can easily be interpreted by a non-specialist.

CHALLENGE 3: SUB-SEA INSPECTION OF GROUTING BETWEEN MONOPILES AND TRANSITION PIECES

Background:

The grout join in a monopile sits between the transition piece and the foundation. It is typically formed of an annulus of concrete between two steel walls.

Grout joints have caused significant problems for wind farm operators and are of concern for most of the UK's offshore wind early monopile fleets. There are currently no means of accessing grout for visual inspection. Current methods for inspecting grout are slow, expensive and have significant health and safety related issues.

Detection & reporting requirements:

- Map of grout & steel thickness
- Map of grout density
- Map of voids
- Map of cracks & fracturing
- Separation of grout from internal steel work
- Water ingress & steel surface corrosion
- Interpretive reporting by inspection contractor is ideally required.

Relevant geometry & materials

- Monopile diameter – 3.5 to 8.0 m diameter
- Steel thickness 40-150 mm
- Grout thickness -20 to 150 mm
- MP/TP overlap length – typically 1.5D
- Steel – typically S355 (for monopiles & TPs)
- Grout – typically high cementitious 'Densit' or similar, potentially stainless fibre reinforced
- Critical zones for inspection include: top and bottom extremes of overlap, shear key locations & taper transition sections

Operating conditions

- Equipment on the outside of the MP/TP must be capable of operating in both the splash zone (inter-tidal) and the fully submerged zone.
- Internal equipment must be capable of operating at the internal waterline and submerged in internal water (not freely circulating seawater).
- External currents up to 4 knots peak can be expected.
- Internal underwater visibility may be very poor.

Access constraints

- **Access onto turbine platform** is by Crew Transfer Vessel CTV); all staff must have relevant offshore and climbing training (requirements TBC by farm operator). Access depends on deployment method, and metocean capability of CTV, ROV and/or the external probe equipment.
- Access to inside of monopile may require airtight lids to be opened. Working inside is categorized as confined space, requiring appropriate safety procedures.
- Anode cages are mounted external to MP, which may impede access.

Other constraints/specifications

- Ultimate aim is to evaluate grout/water ratios, aggregate content and hence grout strength. This is an important input for FE modelling.
- Note that surfaces may have paint coating applied (typically glass flake epoxy or high-build durability epoxy). Worst case could be 1500 microns in the splash zone region.
- Marine growth up to 100 mm can be expected, soft and hard, locally variable, and water depth dependent.
- Inside the monopile there may be J-tubes and cables and other monitoring instrumentation in-situ.

CHALLENGE 4: SUB-SEA INSPECTION OF GROUTING IN JACKET PIN PILES

Background:
Offshore wind jackets are secured to the seabed with pin piles. There are two main arrangements in use; in the first, the jacket is lowered onto pre-driven piles, with the legs being guided inside the piles by stab/guidance plates. In the second, separate pile sleeves are welded to the jacket legs; the jacket is placed on the seabed and levelled and the piles are inserted into the sleeves and driven to depth. In both arrangements, the annulus between the pile and the concentric steel member (either the internal pile or the external pile sleeve) is grouted to form the load path. The integrity of the grouted joint is critical to the structure. German BSH standards can require specific monitoring of the grout integrity of jacket piles. The detection requirements are similar to those for grout monitoring in the MP/TP joint of monopiles.

Detection & reporting requirements:

- Map of grout & steel thickness
- Map of grout density
- Map of voids
- Map of cracks & fracturing

Interpretive reporting by inspection contractor is ideally required.

Relevant geometry & materials

- Pin pile OD – 1.5 to 2.5 m
- Pile wall thickness – 30 to 80 mm
- Pile material – Grade S355, occasionally higher strength
- Pile sleeve ID – 2.0 to 3.0 m
- Pile sleeve wall thickness – 40 to 80 mm
- Pile sleeve material – Grade S355 typically
- Grout annulus – 200 to 350 mm
- Grout material – high strength cementitious grout
- Overlap length – complete overlap length is typically 6.0 m to 8.0 m, however only the section between the mudline and stopper plate is accessible, so approx. 1.0 m to 4.0 m

Verification of the integrity of the top of the grouted connection is of prime interest (refer to ISO 19902 which defines the minimum required length of the effective grout over the uppermost shear keys).

Operating conditions

- Joint is fully submerged
- Water depth up to ~50 m
- External currents up to ~4 knots peak
- Mudline visibility may be poor

Access constraints

- Whilst jackets are fitted with access platforms similar to monopile foundations, access to the grouted connection is likely to have to be via ROV/AUV/diver.
- Geometry of the pile stopper could affect accessibility to the upper section of the grouted connection.
- The connection has several appurtenances that may constrain access – ROV handles, anodes, grout pipes and connectors.
- J-tubes, bell-mouths and cable protection systems may be located near the grouted connection, and the local area may be surrounded by scour protection e.g. rock armour and filter layers.

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Other constraints/specifications

- Ultimate aim is to evaluate grout/water ratios, aggregate content and hence grout strength. This is an important input for FE modelling.
- Note that surfaces may have paint coating applied (typically glass flake epoxy or high-build durability epoxy). Worst case could be 500 microns in the submerged region
- Marine growth up to 100 mm can be expected, soft and hard, locally variable, and water depth dependent.