G+ Safe by design

Workshop report: WTG access to the transition piece (below airtight deck)

G+ Global Offshore Wind Health & Safety Organisation

In partnership with

energy institute

G+ SAFE BY DESIGN

WORKSHOP REPORT: WTG ACCESS TO THE TRANSITION PIECE (BELOW AIRTIGHT DECK)

First edition

November 2018

Published by
Energy Institute, London
The Energy Institute is a professional membership body incorporated by Royal Charter 2003
Registered charity number 1097899

The Energy Institute (EI) is the chartered professional membership body for the energy industry, supporting over 20 000 individuals working in or studying energy and 250 energy companies worldwide. The EI provides learning and networking opportunities to support professional development, as well as professional recognition and technical and scientific knowledge resources on energy in all its forms and applications.

The EI's purpose is to develop and disseminate knowledge, skills and good practice towards a safe, secure and sustainable energy system. In fulfilling this mission, the EI addresses the depth and breadth of the energy sector, from fuels and fuels distribution to health and safety, sustainability and the environment. It also informs policy by providing a platform for debate and scientifically-sound information on energy issues.

The EI is licensed by:

– the Engineering Council to award Chartered, Incorporated and Engineering Technician status;
– the Society for the Environment to award Chartered Environmentalist status.

It also offers its own Chartered Energy Engineer, Chartered Petroleum Engineer and Chartered Energy Manager titles.

A registered charity, the EI serves society with independence, professionalism and a wealth of expertise in all energy matters.

This publication has been produced as a result of work carried out within the Technical Team of the EI, funded by the EI's Technical Partners. The EI's Technical Work Programme provides industry with cost-effective, value-adding knowledge on key current and future issues affecting those operating in the energy sector, both in the UK and internationally.

For further information, please visit **http://www.energyinst.org**

The EI gratefully acknowledges the financial contributions towards the development of this publication from members of the G+ Global Offshore Wind Health and Safety Organisation

Ørsted
EDF
E. ON
Equinor
Innogy
Scottish Power Renewables
SSE
Vattenfall

However, it should be noted that the above organisations have not all been directly involved in the development of this publication, nor do they necessarily endorse its content.

ISBN 978 1 78725 021 5

Published by the Energy Institute

Front cover image provided by Stowen

Hard copy and electronic access to EI and IP publications is available via our website, **https://publishing.energyinst.org**.
Documents can be purchased online as downloadable pdfs or on an annual subscription for single users and companies.
For more information, contact the EI Publications Team.
e: **pubs@energyinst.org**

CONTENTS

LIST OF FIGURES AND TABLES

Page

Figures

Tables

1 EXECUTIVE SUMMARY

The latest G+ Global Offshore Wind Health and Safety Organisation (G+) Safe by Design workshop focused on the issues associated with access below the airtight deck in a Wind Turbine Generator (WTG). This included the design/infrastructure of the WTG and human factors. The workshop, comprising several data gathering and data analysis activities, was held in Berlin on 23 May 2018. The workshop format was developed to explore reasons for access below the airtight deck in monopiles and the associated hazards and issues, with a focus on the Safe by Design principles.

Across the workshop, many common and interrelated issues and associated recommendations were identified, and these are shown in 1.1.

1.1 RECOMMENDATIONS

- An approach of 'we don't go below the airtight deck often, so it doesn't need to be perfect' by foundation designers was perceived. This could be explored further to determine if this is an industry-wide perception and if so identify ways of addressing that perception with direct input from technicians.
- It is believed that offshore wind farm owners and operators are not always actively involved or engaged with the development of industry standards. It is recommended that this is reviewed in conjunction with the WTG original equipment manufacturers (OEMs) to determine if this is the case and if so, develop a strategy for both parties to provide input, as they have the most knowledge on activities and hazards associated with inspections below the airtight deck.
- The G+ could facilitate an industry-wide effort to identify and demonstrate remote inspection and robotics that could be or are being used to perform work below the airtight deck for current and future wind farms, hence limiting the number of technician visits below the airtight deck.
- As the foundation ladder may be designed differently to ladders in the rest of the turbine, there are specific features of the sub-structure environment that are not fully covered in the working at heights training. The industry may benefit from a more tailored course that focuses on ladder climbing and hazards within the Transition Piece (TP) and monopile. Alternatively, existing training courses could be updated to include these issues. Additionally, the design of foundation ladders could be reviewed to ensure alignment with other access area health and safety (H&S) systems/requirements. G+ should facilitate discussion on this area.
- Industry-wide knowledge sharing of issues encountered, how these were solved, what works and what doesn't with regard to activities below the airtight deck would help to improve the current operation and maintenance (O&M) activities and future monopile designs, both in terms of H&S and cost. This could be targeted at particular areas, for example, a comparison of ventilation of monopiles. Additionally, the development of a guidance document on access and working below the airtight deck could be useful.
- Musculoskeletal disorders were identified as a significant issue associated with working below the airtight deck (and many other areas of a WTG). A G+ Safe by Design workshop exploring this topic more fully could be beneficial.

- The G+ could facilitate a study into the benefits of using remote, real-time monitoring below the airtight deck, as it is not completely clear whether the use of remote, real-time monitoring equipment below the airtight deck would reduce the number of visits by technicians.

2 BACKGROUND AND INTRODUCTION

2.1 BACKGROUND

The G+ comprises the world's largest offshore wind developers who have come together to form a group that places health and safety at the forefront of all offshore wind activity and development. The primary aim of the G+ is to create and deliver world class health and safety performance across all its activities in the offshore wind industry. The G+ has partnered with the Energy Institute (EI) to develop materials including good practice guidelines to improve health and safety performance. Through sharing and analysis of incident data provided by G+ member companies, an evidence-based understanding of the risks encountered during the development, construction and operational phases of a wind farm project has been developed. This information has been used to identify the health and safety risk profile for the offshore wind industry.

In 2014, the Crown Estate asked the G+ to take over the running and delivery of their Safe by Design workshops. The Crown Estate had run a number of these previously, covering topics such as diving operations, lifting operations, wind turbine design and installation and the safe optimisation of marine operations.

By bringing the Safe by Design workshops into the G+ work programme, the G+ aims to explore industry operations and technologies with a focus on Safe by Design principles. The G+ workshops examine the current design controls relating to a topic, discuss where current design has potentially failed, identify opportunities for improvement and then seek to demonstrate the potential risk reduction to be gained from these new ways of thinking and operating.

To date six workshops have been held under the auspices of the G+ covering: marine transfer/access systems, escape from a nacelle in the event of a fire, lifting operations, service lifts, davit cranes, and access/egress in a WTG. The outputs from five of these workshops have been made available in reports which can be downloaded from the G+ website to be used as a reference by the industry.

https://www.gplusoffshorewind.com/work-programme/workshops

2.2 INTRODUCTION

From data analysis and feedback received by the G+, access below the airtight deck within a WTG was identified as an area that should receive additional focus. Therefore, under the direction of the G+ Focal Group, a Safe by Design workshop on this subject was held on 23 May 2018 in Berlin, Germany.

The outputs from this workshop are documented in this report.

3 METHOD/ATTENDANCE/AGENDA

3.1 METHOD

A one-day workshop was held on 23 May 2018 in Berlin, bringing together stakeholders from across the industry to consider the issues associated with access below the airtight deck in a WTG in the offshore environment. This was focused on monopiles, which make up most of the current installations. After opening remarks from Frank Monaghan, Health and Safety Director, ScottishPower Renewables, the workshop commenced with a short presentation providing the top-level details of the workshops exercises that followed, as shown here.

Exercise 1 – Activity and Hazard Identification (HAZID)

- Brainstorming techniques were used to identify the activities undertaken below the airtight deck in a WTG, by whom, how frequently and in which life cycle phase.
- This was followed by identification of the main hazards associated with these activities. The most significant activities and hazards were explored further in Exercise 2.

Exercise 2 – Hazard analysis

- The most significant activities and hazards were interrogated to identify the design issues causing the hazards.
- The current controls that are in place to control these hazards were also identified.

Exercise 3 – Hierarchy of control

- In the final exercise, the most significant activities and hazards were analysed further with respect to the hierarchy of control.
- This resulted in suggestions for how each of these activities/hazards could be eliminated or substituted.

The attendees were split into three groups and all participated in each of these exercises.

At the end of the day the initial findings and conclusions were presented to the attendees in a plenary session, before concluding the workshop. The full findings and conclusions are included in this report.

3.2 AGENDA

Workshop opening remarks

Frank Monaghan, Health and Safety Director, ScottishPower Renewables

G+ incident data – what is the evidence telling us?

Beate Hildenbrand, Manager – Offshore Wind, Energy Institute

Foundation design and the need to access the foundations

Cristina Navarro, Engineering Manager – East Anglia One, Iberdrola Renewables and Michael Crawford, H&S Consultant ScottishPower Renewables

Workshop exercises introduction and overview

Gordon Stewart, SHEQ Manager – Offshore Renewable Energy Catapult

Workshop exercises

Each exercise led by an ORE Catapult facilitator; Owen Murphy, Conaill Soraghan and Roberts Proskovics

Management of H_2S Gas in Wind Turbine Sub-Structures

Conaill Soraghan, Project Engineer, O&M Systems, ORE Catapult

Plenary session – Presentation on key findings/outputs from workshop

Closing remarks

Frank Monaghan, Health and Safety Director, ScottishPower Renewables

3.3 ATTENDANCE

Erica Lindell	E.ON
Marcus Peters	E.ON
Garry Bradford	EDF
Beate Hildenbrand	Energy Institute
Kishan Kansara	Energy Institute
Hakon Graven	Equinor
Fritz Wiedemann	Equinor
Tony Lyon	G+
Beth Rawson	HSE
Darren Tape	Innogy
Conaill Soraghan	ORE Catapult
Gordon Stewart	ORE Catapult
Owen Murphy	ORE Catapult
Roberts Proskovics	ORE Catapult
Hasse Andreasen	Ørsted
Karsten Kristensen	Ørsted
Neils Peterson	Ørsted
Christopher Brons-Illing	Ramboll
Christian Seeberg-Braun	Siemens Gamesa Renewable Energy (SGRE)
Bob Hammond	SPR
Cristina Navarro	SPR
Frank Monaghan	SPR
Michael Crawford	SPR
Bruce Turner	Transmission Investment
Martin Fuller	SSE
Nilasmandrup Hansen	Vattenfall

4 WORKSHOP EXERCISES SUMMARY

The workshop comprised three exercises, covering:

– Activity and hazard identification – Identification of the activities performed below the airtight deck and the associated hazards.
– Hazard analysis – Identification of the design issues causing the hazards, along with the current controls.
– Hierarchy of control – Applying the hierarchy of control to identify how these activities/hazards could be eliminated or substituted.

The attendees were split into three groups and all attendees participated in each of these exercises.

Note – the full results and details of the exercises are shown in Annex A.

ANNEX A
DETAILED WORKSHOP NOTES

A.1 WORKSHOP EXERCISE 1: ACCESSING TRANSITION PIECE (BELOW AIRTIGHT DECK)/ FOUNDATIONS AND ASSOCIATED HAZARDS

A.1.1 Purpose

The purpose of this exercise was to identify activities undertaken below the airtight deck in the TP and in the monopile. For each identified activity, the associated hazards were also identified. Where available, further information on these activities, such as how often these are performed, life cycle phase of the activity and additional comments from workshop participants were also captured.

The most significant activities and hazards (as prioritised by the workshop participants' votes) were then taken to Exercise 2 for hazard analysis.

A.1.2 Outputs

A.1.2.1 Evidence

See Table A1 for a list of activities and associated hazards that were identified in the first workshop session.

Table A1: List of activities and associated hazards

<table>
<tr><th>Activity</th><th>By whom?</th><th>Frequency/ when?</th><th>Associated hazards</th><th>Life cycle phase/ additional comments</th></tr>
<tr><td>Grouting or bolt tensioning</td><td rowspan="7">– Technicians
– Subcontracted technicians
– QC inspectors
– Regulator visit
– Client representative
– Specialist technicians
– Divers
– Rescue team</td><td rowspan="7">High intensity for construction activities (short duration per project by rolling exposure from one project to next)</td><td rowspan="7">– Confined/ restricted space
– Difficult access and egress
– Working at heights
– Falls
– Falling/ dropped objects
– Oxygen depletion/ atmospheric</td><td rowspan="6">Construction

Tower installation activity applicable to some bolted connection designs</td></tr>
<tr><td>Cable pull-in</td></tr>
<tr><td>Tower installation</td></tr>
<tr><td>Cable termination</td></tr>
<tr><td>Sealing/hatches</td></tr>
<tr><td>Fit out work</td></tr>
<tr><td>Corrosion protection installation</td><td>Construction or O&M</td></tr>
</table>

Table A1: List of activities and associated hazards (continued)

<table>
<tr><th>Activity</th><th>By whom?</th><th>Frequency/ when?</th><th>Associated hazards</th><th>Life cycle phase/ additional comments</th></tr>
<tr><td>Inspection
– Grout and bolt tension
– Tower interface
– Statutory inspection
– Corrosion (water/oxygen level)
– Weld inspection
– Non-destructive Testing (NDT)
– Equipment maintenance
– Seal inspection</td><td rowspan="6"></td><td>Annual inspection (continuous exposure of the same team)
Design dependent (from 1–25 yearly)</td><td rowspan="6">– Drowning
– Ergonomics
– Manual handling
– Fatigue/ working hours
– Unfamiliar environment
– Weather extremes
– Visibility/ lighting
– Crush injuries (bolt torqueing)
– Hazardous substances
– Noise
– Vibration
– Slips and trips
– Lifting operations
– Cargo
– Electricity/ high voltage
– Rope access Diving
– Gases (light and/or heavy) fire
– Explosion
– Hazardous substance
– Lack of experience/ competency</td><td>Planned and unplanned
Over-engineering can mitigate necessity for these</td></tr>
<tr><td>Remediation
– Cable seals
– Grout or bolt tension failure
– Cathodic protection
– Ventilation</td><td rowspan="4">When required</td><td>Largely unplanned O&M work</td></tr>
<tr><td>(Emergency) Rescue, Emergency evacuation</td><td>Any life cycle phase</td></tr>
<tr><td>Mould, algae cleaning*</td><td rowspan="2">O&M</td></tr>
<tr><td>Biological/ Chemical reaction (e.g. H_2S gas build-up) mitigation*</td></tr>
<tr><td>Decommissioning</td><td>End of life</td><td>Decommissioning</td></tr>
</table>

* Both activities are highlighted separately from inspection and remediation due to being biological and not commonly associated structural hazards. Additionally, H_2S gas build-up is known to have occurred in monopiles below the airtight deck.

A.1.2.2 Analysis and findings

A large number of activities, from construction to decommissioning, requiring personnel descending below the airtight deck were identified. Most of the activities fall under O&M, followed by construction, and decommissioning. This order reflects stakeholder experience, with decommissioning not split into further activities due to limited know-how in decommissioning of offshore wind turbines to date.

The list of activities split by life cycle phases is shown in Figure A1. It should be noted that Figure A1 does not reflect the likely frequency, duration or repetition (e.g. construction technicians performing activities on a daily basis versus maintenance technicians performing activities below the airtight deck on a yearly or five-yearly basis) of the activities.

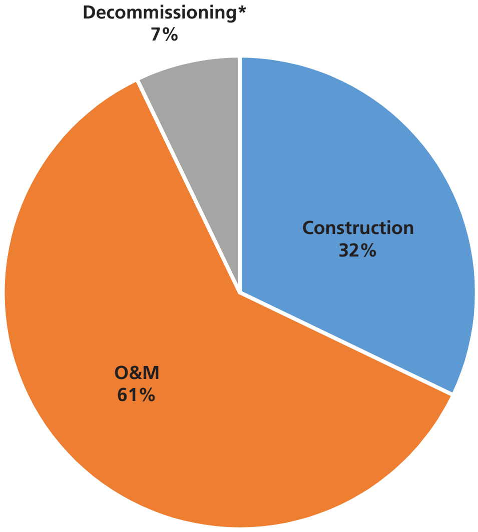


Figure A1: Identified activities split by life cycle phase

* Decommissioning has only two activities assigned against it due to very limited experience of performing monopile decommissioning.

The hazards identified vary significantly. With the exception of the diving hazard, which is only associated with divers, all other hazards can impact any personnel performing work or rescue below the airtight deck.

The frequency of activities performed is highly design-specific. As multiple different stakeholders with projects at various stages along their life were present at the workshop, except for legal and statutory inspections, it was difficult to place a specific frequency number against different tasks in the O&M phase. However, a clear design intent to reduce the number of visits below the airtight deck in new designs (e.g. five-yearly in some cases) was shown by the workshop participants.

A silo-based design approach is perceived to be used in the industry, including in the design of monopiles. Without engagement and communication with all stakeholders this can lead to suboptimal designs, which are not fully fit for purpose, and consequently result in an increased number of potential H&S hazards. As highlighted by the workshop participants, airtight decks are often not optimally designed to facilitate access. They were possibly designed with little engagement with technicians and assuming that they will not be accessed regularly, which is not the case for many projects.

Standards defining the number of inspections to be made below the airtight deck are potentially written by people with limited operational experience, potentially leading to an unnecessarily large number of inspections below the airtight deck. Similarly, onerous warranty requirements can often lead to a large number of inspection activities, which can be of low value. This was further confirmed by a workshop participant saying: 'An engineer will always want to look at something, but do we really need to?'

The key activities, sub-activities and hazard groups are shown in Figure A2.

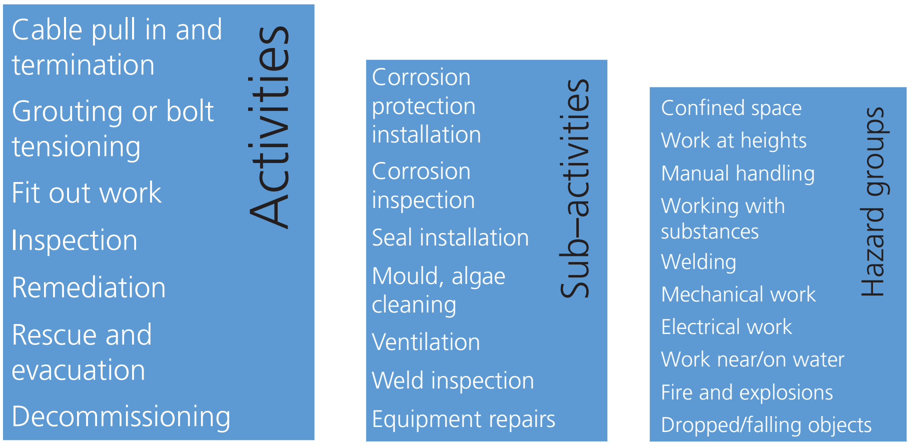


Figure A2: Key activities, sub-activities and hazard groups associated with access below airtight deck

A.1.2.3 Recommendations and outputs

The following thoughts, considerations and recommendations were developed during Exercise 1. The refined report recommendations are shown in the Executive Summary.

- Technician height, tasks to be performed, and input from technicians should be considered when designing the airtight hatch, and the decks and structure around it to improve ergonomics. For examples, access hatches are often not flush with the floor and technicians can trip on them.
- 'We don't go below the airtight deck often, so it doesn't need to be perfect' – approach by foundation designers was perceived. This could be explored further to determine if this perception can be changed and if so, identify ways of improving it with input from technicians.
- Offshore wind farm owners and operators should be consistently sought by the WTG OEMs to provide input when developing industry standards, as they have the most knowledge on activities and hazards associated with inspections below the airtight deck.
- It is important to recognise and consider that different technicians will have varying exposure to activities below the airtight deck. For example, although a foundation installation may only last a few days in the life of the turbine, a technician most likely performs the same job repeatedly (e.g. grouting). The other extreme is visits which are relatively infrequent, making technicians unfamiliar with the environment below the airtight deck.

– Decommissioning should be considered in detail when developing designs of monopiles and TPs, to reduce the number of issues associated with activities below the airtight deck that may be encountered during the decommissioning stage.

A.2 WORKSHOP EXERCISE 2: HAZARD ANALYSIS

A.2.1 Purpose

The purpose of this exercise was to analyse hazardous activities that occur within the TP and monopile at offshore wind farms with a focus on the design issues causing them. The approach involved drilling into the prioritised hazardous activities identified in the previous workshop exercise. For each hazardous activity, the workgroup explored the design issues causing the hazardous activity and any control measures that are currently in place. Throughout the discussion, any relevant additional comments were recorded.

A.2.2 Outputs

A.2.2.1 Evidence

See Table A2 for a list of design issues causing hazardous activities that were identified in the second workshop session.

Table A2: Design issues causing hazardous activities

Hazardous activity	Design issue	Current control measure	Additional comments
Remediation works – Cable seals – Grout failure – Cathodic protection – Adding/altering ventilation	– Outgrown design codes – Incorrect assumption of airtight seal	– Design for free ventilation/flushing and accept free corrosion	– Consider foundation as 'part of machine' and consider the application of the Machinery Directive. This is particularly good for access/work at height

Table A2: Design issues causing hazardous activities (continued)

Hazardous activity	Design issue	Current control measure	Additional comments
Inspections – Bolted connections – Grouted connections – Tower interface – Statutory inspections – Corrosion – Welds	– Design did not consider or prioritise minimal inspection activity – Design philosophy did not seek to minimise re-tensioning of bolts – Corrosion allowance uncertain – Any critical material and component interfaces will require inspection – Steel will rust therefore anode placement and replacement necessary – Coatings not sufficient for 25 years – Coatings can be hazardous	– Sample % of foundations only – Try to think ahead – Confidently establish actual corrosion rate – Remotely operated vehicles (ROVs) – Move to risk/condition based as opposed to time-based inspections – Work permits and planning – Training and competency – Escape training – Standards sometimes available – Personal protective equipment (PPE)	– Is it too early to be basing sample % on operational history? Can it be built into specification? – There is a difference between a quick check and labour-intensive re-tensioning – Monitoring technology from other industries – Keep it simple/reliable – Can other materials be considered? – The design should be challenged. Owners should demand maintenance-free designs. The target should be to avoid sending people offshore – All the recorded grout issues have driven designs towards bolted connections – Rate of depletion of anodes can be driven by waves – Coating spray is not perfect
Working in confined spaces, particularly monopile foundations	– Interpretation of what is a confined space – Design and location of switchgear – Eliminate the need for people to go into a confined space	– Consider which part of the world you are in as standards and procedures change – Existing and emerging standards	– Almost achieving no requirement to access in some new designs – What is appropriate training? – Current control measures may need excess people in/near hazardous area – Standards progression is very slow

Table A2: Design issues causing hazardous activities (continued)

Hazardous activity	Design issue	Current control measure	Additional comments
Activity in the presence of hazardous gases – H_2S – CO – Methane – CO_2 – Chlorine	– Microbial decomposition – Forcing a monopile into sediment will trap water and sediment leading to the risk of stagnant water and sediment due to oxygen depletion – Corrosion protection causes chemical reactions with undesirable by-products – Unclear how to ventilate and where to ventilate to	– Monitoring – PPE and respiratory protective equipment (RPE) – Retrofitted ventilation – in some cases operators have cut a new hatch/ opening in the foundation	
Ergonomics – Bending and twisting – Manual handling and lifting	– The design is not prioritised for access and egress. This needs to be considered in early designs – Manual handling suffers due to lack/position of hook-on points, lifting points, anchor points, ladders etc.	– Convoluted rope/ slinging set-ups – Retrofitting additional hang-off points and load-bearing plates	– Working at heights should be tailored to foundations to support these activities. The design of foundation ladders needs to be reviewed to ensure alignment with other access area H&S systems/ requirements. – There is a very important need to collect data about the strain that techs are under to understand musculoskeletal risks. Job- or task-specific analysis is required to support investment in legacy turbines and differentiate the workforce

Table A2: Design issues causing hazardous activities (continued)

Hazardous activity	Design issue	Current control measure	Additional comments
Rescue and emergency escape – Restricted access – Atmospheric hazards – Manual handling – Rope access – Confined space – Working at height – Dropped objects – Slips and trips – Diving – Access and egress – Electrical – Fire	– Lack of standards – Overlapping standards – Restricted space – Poor access ways – Need to use ladder	– Light – Communications – Procedures – Design reviews – Training – PPE	
Installation works – Grout – Bolt – Tower – Cables – Fit out – Seals, hatches			

A.2.2.2 Analysis and findings

The analysis of hazardous activities within TPs and monopiles to identify the root cause design issues revealed a set of design principles that should be adhered to:

– Design should aim for the complete removal of people within the substructures.

– Design should aim for zero maintenance requirement over the full 25-year life cycle.

– Keep designs simple to minimise unforeseen issues and any complications if access is ultimately required.

It is apparent that the existing monopile and TP designs may not have consistently applied a similar set of principles because the sub-structures are not prioritised for access/egress with small hatches and confined spaces; however, potential design issues have led to a higher than expected volume of personnel having to access these areas. The main drivers of this unforeseen access are widespread grouted connection slippage and internal monopile corrosion. Consequently, there is significant access required for inspections and remedial works.

The most significant and common design issues that were identified are illustrated in Figure A3.

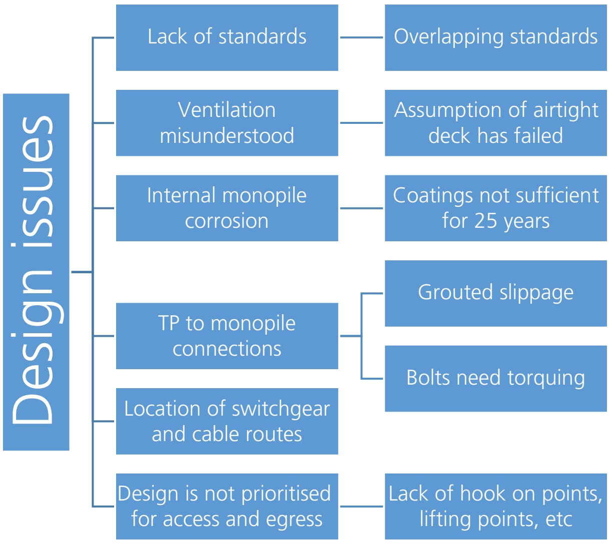


Figure A3: Main design issues identified

Given the design assumption of minimal access, there is, in some cases, a lack of hook-on points, lifting points, anchor points and ladders. This is leading to the adaption of convoluted rope/slinging set-ups and retrofitting additional hang-off points and load-bearing plates. Furthermore, the equipment and components such as cathodic protection anodes being manually handled in the awkward environment is inconsistent and the impacts on long-term technician wellbeing are unknown.

Some workshop participants suggested considering foundations as part of WTG, hence making the Machinery Directive applicable to foundations. This could be particularly beneficial for improving access and work at height in foundations, including below the airtight deck. This is a suggestion that would need to be explored further to determine the legal basis of such a decision.

Current control measures include procedures, planning and PPE as expected. Minimising human intervention is key and remote monitoring and robotics solutions are emerging and already exist in other industries to address this issue. However, they need to be tested to provide confidence that they are robust and effective. Additionally, moving to risk- or condition-based maintenance would have a significant positive impact due to the expected reduction in visits.

A common hazard is the lack of knowledge and information. The main technical areas where this is a problem are corrosion, the development of hazardous gases and the long-term impact of manual handling. In particular, the risk of long-term musculoskeletal issues due to manual handling needs to be investigated. Data are needed to help in solving the problem.

Lessons from operations need to be fed back into design. It was noted that progress is being made with almost no requirement to access in some new designs. However, there remains the challenge of the approximately 15 GW of existing plant in Europe with legacy issues and the unknown future for the end-of-life phase for the newer designs. It was generally accepted that standards and design improvements change slowly and there will always be unforeseen technical issues, especially approaching end of life so access will continue to be required.

A.2.2.3 Recommendations and outputs

The following thoughts, considerations and recommendations were developed during Exercise 2. The refined report recommendations are shown in the Executive Summary.

- There appears to be an industry need for a facility that can allow remote monitoring and robotics solutions to be developed and/or adapted from other industries to give confidence to the offshore wind industry that they are applicable and that they could be used successfully.
- There are specific features of the sub-structure environment that are not fully covered in the working at heights training. The industry may benefit from a more tailored course that focuses on ladder climbing and hazards within the TP and monopile. Alternatively, existing training courses could be updated to include these issues. Additionally, the design of foundation ladders could be reviewed to ensure alignment with other access area H&S systems/requirements.
- Considering foundations as part of WTG, hence making the Machinery Directive applicable to foundations could be beneficial for improving access and work at height in foundations, including below the airtight deck. This is a suggestion that would need to be explored further to determine the legal basis of such a decision.
- One area of identified inconsistency across offshore wind farms is the design and retrofitted amendments to monopile ventilation. A comparison of ventilation of monopiles would be prudent to understand what has been tried and what is effective.
- It would be useful to collect data about the strain that technicians are under when carrying out manual handling in the sub-structure to understand the risk of musculoskeletal issues. Job- or task-specific analysis would also help to support targeted investment in legacy turbines to ensure tasks remain safe to undertake.
- Musculoskeletal disorders were identified as a significant issue associated with working below the airtight deck (and many other areas of a WTG). A workshop exploring this topic more fully could be beneficial.

A.3 WORKSHOP EXERCISE 3: HIERARCHY OF CONTROLS

A.3.1 Purpose

The purpose of this exercise was to apply the top two levels of hierarchy of controls (elimination and substitution), as shown in Figure A4, to the identified activities and associated hazards in Exercises 1 and 2, respectively. Each group chose several activities and hazards from Exercise 1 and applied the hierarchy of control to each, starting with elimination and followed by substitution. These were captured by a group's scribe and shared with all workshop participants by a group's spokesperson at the feedback session.

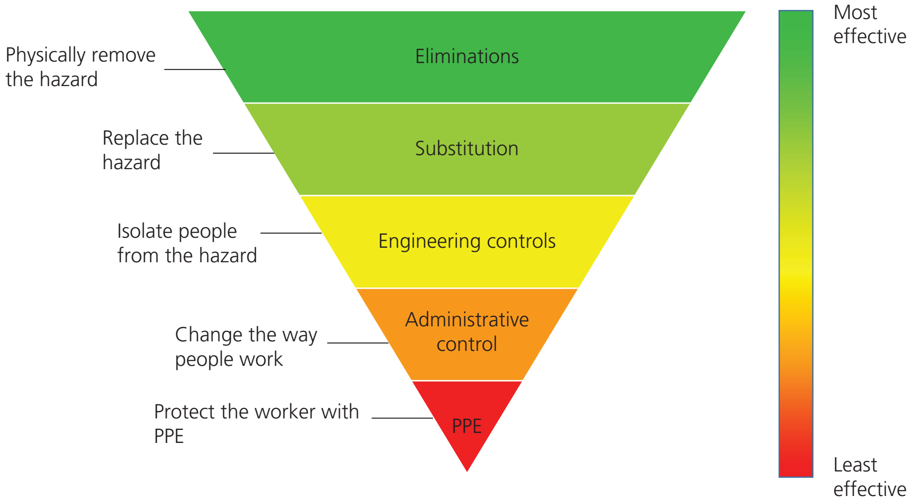


Figure A4: Hierarchy of controls by IOSH

A.3.2 Outputs

A.3.2.1 Evidence

See Table A3 for a list of hazard eliminations and substitutions that were identified in the workshop session.

Table A3: Hazard elimination and substitution

Activity/ hazard	Elimination	Substitution	Additional comments
Manual handling and ergonomics	– Design to allow use of mechanical aids – Do as much work as possible onshore (particularly for construction) – Design for maintenance – No activities in airtight deck – Ensure sufficient space – Taking examples from other industries	– Cranes or power lifting equipment – Wider foundation – Anchor points in a number of locations	– Secure budgets – Ensure enough space and equipment in the correct location – Collect data, real-time monitoring (needs to be reliable) – Understand ergonomic impact (e.g. being proactive – understanding the impact, having the right people for the job)
Confined spaces	– Design not to include any confined space – Design to minimise requirement to enter confined space – Holistic risk-based approach by considering all risks together	– Handover of design info to operations phase – Proportional reactions to risk – Sharing knowledge	– How to define? – Variance between sites – Quality control – Do you get what you specify? – Larger machines with large diameter monopiles will improve amount of space available
Slips and trips	– Combination of materials considered at design – Management of subcontractors (competent, trusted, good relationship) – Focus on every small detail in design (e.g. lighting, moisture, ergonomics)		– Do they have correct/compatible equipment, PPE? – Need to fight to show value of this, Make sure it is considered early
Mould, fungus, algae	– Installation procedure could be better designed		– Consider cost of cleaning it up, as this might change consideration of how important this is

Table A3: Hazard elimination and substitution (continued)

Activity/ hazard	Elimination	Substitution	Additional comments
Cable installation	– Eliminate requirement to access TP – Earlier design risk assessment – Design change – Pre-installed cables	– Route cables externally – Lessons learned	
Inspections	– Movement of plant/ equipment from below airtight deck – Remote inspection/ monitoring, ROVs to avoid human access and eliminate use of divers – Don't go below the airtight hatch – Different interface/ interface elimination – TP free installation/ design – Drones (size limitation)	– Increase reliability, minimise work offshore – Change material, technology – Real-time monitoring – Increase time between bolt tension checks – Extend statutory inspection dates – Inspect at point of use – Use evidence to justify increased time between inspections – Move connections to outside	– Remote systems must be reliable to have real value – Solution is needed – Talk to/bring systems from other industries – A lot of work is done to maintain warranty/contract of questionable value – Avoid warranty requirements for diver inspection
Remediation work	– Design for free flow of water – Coating to eliminate corrosion – Movement of plant/ equipment from below airtight deck – Remote inspection, ROVs – Change design and requirements, so that there is no necessity to access TP	– Move connections to outside – Use alternative materials (reduce effect of corrosion)	

Table A3: Hazard elimination and substitution (continued)

Activity/ hazard	Elimination	Substitution	Additional comments
Emergency rescue or escape	– Eliminate requirement for persons to access TP		– If it cannot be substituted or eliminated, ensure sufficient hook-on points, access and egress, specialist teams, safe systems of work – Drills
Manufacturing and transport issues, which have impacted foundation/TP		– Lessons learned – Quality control – Assess transport fatigue and storage issues	
Development of hazardous gases e.g. H_2S	– Mitigating corrosive environment – Potential introduction of free flow water device, natural ventilations – Dimensions of holes for water exchange – Changes material of monopile (e.g. hybrid designs – glass, carbon fibre)	– Technology – Air ventilation – Concrete solutions	

A.3.3.2 Analysis and findings

Across all the activities and hazards discussed, three main approaches to hierarchy of controls were noted:

- Remove the necessity to go below airtight deck by means of redesigning assets (mainly applicable to future wind farms).
- Move equipment from below the airtight hatch.
- Holistic review of cable routing (e.g. external cable routing, pre-installed cable).
- Use of new materials to avoid corrosion and potential development of hazardous gases.
- Different or no interface between the monopile and TP (e.g. use external connection between monopile and TP, TP free foundations).
- Use alternative means for inspection and maintenance (current and future wind farms).
- Remote inspection and monitoring (e.g. ROVs, condition monitoring).

- If access of personnel below the airtight deck cannot be designed out, improve safety (current and future wind farms).
- Improving ventilation and lighting.
- Sufficient hook-on points.
- Hatches better suited to technicians/ergonomics.
- Using evidence to justify increased time between inspections and maintenance.
- Doing as much work as possible onshore.
- Use mechanical aids.

Two schools of thought were identified during the workshop. One that believed that access below the airtight hatch can and should be designed out for future monopile wind turbine designs. The other school was of an opinion that the access might be needed in the future (e.g. tackling unknown unknowns) and as such, future designs should account for this by improving H&S of personnel by improving ventilation, access, and other safety features, if they do need to go down the airtight hatch.

A holistic risk-based approach was also identified as useful to the industry to minimise the overall risk profile of access and working on offshore wind turbines. For example, using externally mounted cables would eliminate the need for technicians to go below the airtight deck, but would introduce new risks (e.g. use of divers). Additionally, risk mitigation should be proportional to the risk score (i.e. the cost of risk mitigation should not outweigh the benefits of the control).

A.3.3.3 Recommendations and outputs

The following thoughts, considerations and recommendations were developed during Exercise 3. The refined report recommendations are shown in the Executive Summary.

- Industry-wide knowledge sharing of issues encountered, how these were solved, what works and what doesn't with regard to activities below the airtight deck and their root causes in a database, guidance or other format would help to improve the current and the future monopile designs, both in terms of H&S and cost.
- Development of a guidance document by the G+ on access and working below the airtight deck to help inform the design of the future wind farms would be useful.
- The G+ could facilitate an industry-wide effort to identify and demonstrate remote inspection and robotics that could be used to perform work below the airtight deck for the current and future wind farms, hence limiting the number of technician visits below the airtight deck.
- The G+ could facilitate a study into the benefits of using remote, real-time monitoring below the airtight deck, as it is not completely clear whether the use of remote, real-time monitoring equipment below the airtight deck would reduce the number of required visits by technicians.

ANNEX B PRESENTATIONS

B.1 PRESENTATION 1 – SCOTTISHPOWER RENEWABLES – FOUNDATIONS AND TRANSITION PIECE ACCESS

B.1.1 Executive summary

This presentation was provided to highlight the design characteristics of offshore foundation and TP structures when people are required to enter restricted spaces. It also contains an overview of the hazards identified with the jacket foundations for East Anglia ONE Offshore wind farm and the design controls in place to mitigate hazards. This presentation focused on monopile structures as almost 70 % of the UK offshore wind farms have monopile foundations.

By incorporating safety within design phases and lessons learnt from previous projects, it identified the need for improved interfaces to ensure designs consider the right questions during the project HAZID processes – safety vs cost.

This presentation provides an overview on the following:

– Different types of foundations used offshore, from the proven design of monopile foundations which has long been the default choice for sea depths of up to 25 m, through to jacket foundations with their intricate multiple welded joints which are time consuming to build and coat with anticorrosion treatments for greater water depths. It is anticipated that the UK offshore industry will require a greater number of jackets for round 3 developments.
– The reasons why access is required within transition pieces and foundations from construction through operation and maintenance to decommissioning.
– Hazards identified and design controls in place to mitigate these hazards. With examples of access/egress hazards and controls for East Anglia jacket foundations, ranging from CTV transfer on to structures, working in restricted and confined spaces to effective emergency management of these activities.

A key message is that it is critical to ensure that health and safety and lessons learned are considered from the initial design stage and throughout all phases of a project to eliminate, reduce or control foreseeable risks.

SCOTTISHPOWER HEALTH & SAFETY ESSENTIALS

SCOTTISHPOWER

East Anglia ONE Offshore Windfarm
Foundations & Transition Piece Access

- We follow our processes, rules and procedures
- We promote health and wellbeing in and outside work
- We only undertake work we are competent to do
- We look out for each other and work as a team
- We think before we act – assess and control the risks

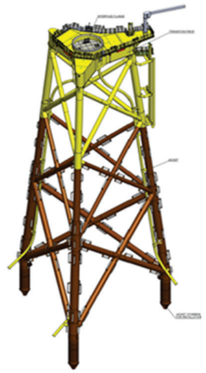
SCOTTISHPOWER www.scottishpower.com Template for corporate and business use/ July 2015 / 2

Agenda

1. Different types of Foundations used Offshore
2. Reasons why we require to access Foundations
3. Potential hazards identified and design controls in place to mitigate hazards
4. Examples

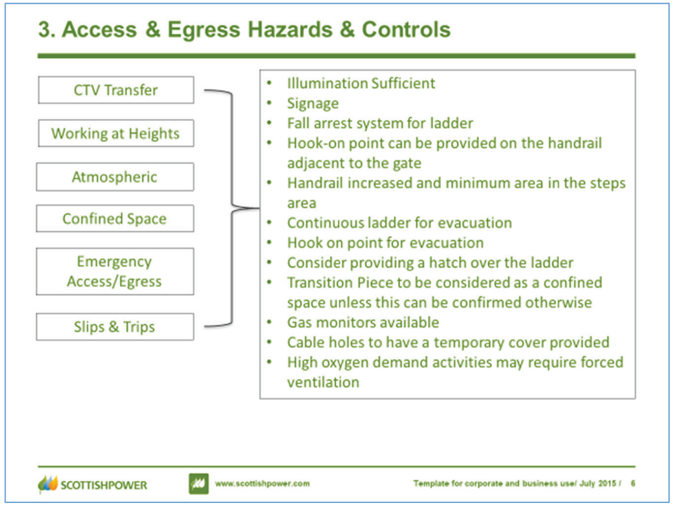
SCOTTISHPOWER www.scottishpower.com Template for corporate and business use/ July 2015 / 3

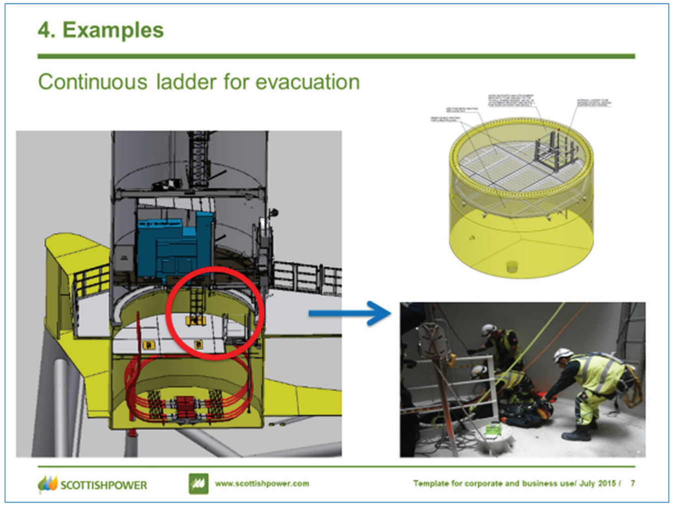
Different types of Offshore Foundations

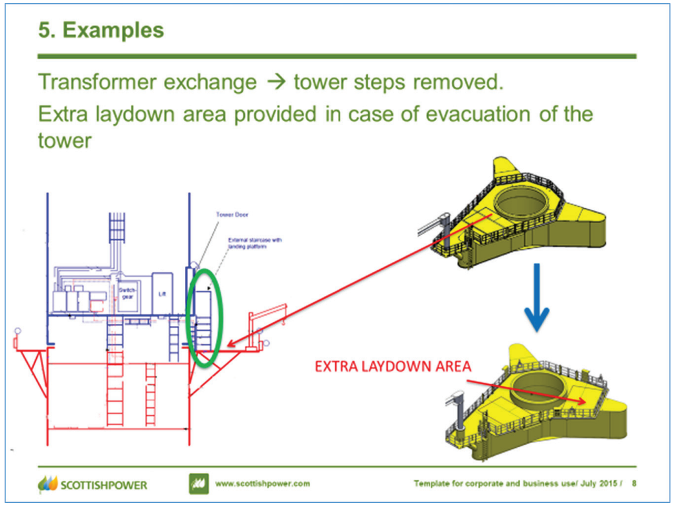


SCOTTISHPOWER www.scottishpower.com Template for corporate and business use/ July 2015 / 4


2. Reasons why access is needed
• Construction and Installation
• Operation and Maintenance
Inspection activities
Monitoring activities
Maintenance
SCOTTISHPOWER
www.scottishpower.com
Template for corporate and business use/ July 2015 / 1


3. Access & Egress Hazards & Controls
CTV Transfer
Working at Heights
Atmospheric
Confined Space
Emergency Access/Egress
Slips & Trips
• Illumination Sufficient
• Signage
• Fall arrest system for ladder
• Hook-on point can be provided on the handrail adjacent to the gate
• Handrail increased and minimum area in the steps area
• Continuous ladder for evacuation
• Hook on point for evacuation
• Consider providing a hatch over the ladder
• Transition Piece to be considered as a confined space unless this can be confirmed otherwise
• Gas monitors available
• Cable holes to have a temporary cover provided
• High oxygen demand activities may require forced ventilation
SCOTTISHPOWER
www.scottishpower.com
Template for corporate and business use/ July 2015 / 6


4. Examples
Continuous ladder for evacuation
SCOTTISHPOWER
www.scottishpower.com
Template for corporate and business use/ July 2015 / 7


5. Examples
Transformer exchange → tower steps removed.
Extra laydown area provided in case of evacuation of the tower
Tower Door
EXTRA LAYDOWN AREA
SCOTTISHPOWER
www.scottishpower.com
Template for corporate and business use/ July 2015 / 8


East Anglia ONE: What is a good outcome?
That the East Anglia ONE project is delivered safely and successfully, achieving zero harm to all our employees and contractors along with improving industry safety standards for designing, constructing and operating a world class offshore windfarm.
IBERDROLA
SCOTTISHPOWER
www.scottishpower.com
Template for corporate and business use/ July 2015 / 9

B.2 PRESENTATION 2 – ORE CATAPULT – MANAGEMENT OF HYDROGEN SULFIDE (H_2S) IN WIND TURBINE SUB-STRUCTURES

B.2.1 Executive summary

This presentation was provided to showcase one of the reasons why offshore wind turbine sub-structures need to be accessed throughout the O&M phase of the project life cycle; namely the investigation and management of hydrogen sulfide (H_2S) generated from within monopiles. The wind farm is Teesside Offshore Wind Farm which is owned by EDF and the ORE Catapult published a case study regarding this issue in 2016.

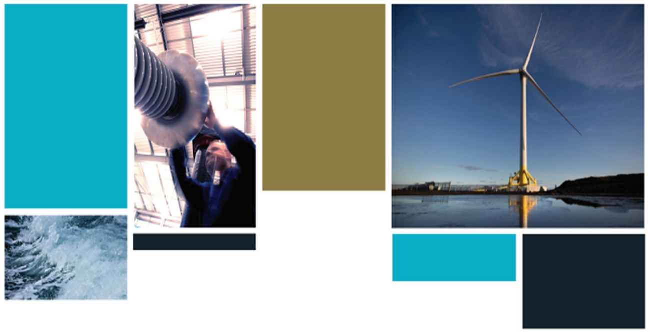
In the first week of operations in 2013, EDF identified H_2S at site – a poisonous, corrosive and flammable gas. A full site investigation revealed that:

- The airtight platform (between the transition piece and the monopole) was leaking on some turbines.
- The H_2S was being produced as a by-product of a reaction between microbes in the sea water and the internal cathodic protection (CP) system.
- The conditions that lead to H_2S and its impact on integrity, particularly corrosion, are not well understood.
- The CP was under-protecting the top and bottom of the monopiles and over-protecting a region in the middle of the monopile.
- The ventilation system was not fit for purpose on some turbines, and it was designed to ventilate hydrogen as opposed to H_2S.

EDF are carrying out the following actions as a result of this investigation:

- Obtaining revised fatigue lives using stress cycle (S-N) curves for free corrosion, for welds subject to tidal exposure or lack of protection from the CP system.
- Modification of the internal CP system to extend the coverage of protection and make the protection potential distribution more uniform across the height of the monopile. Also exploring control of CP potentials through diodes to reduce over-protected zones (to significantly reduce gas production).
- Modification of the internal passive ventilation system to improve its effectiveness and mitigate all gas build-up.
- Introduction of monopile flushing to remove the acidic water condition and H_2S gas production.

A key message here is that the management of H_2S has been a risky and costly issue to manage and it was largely unforeseen at the design stage. It has been the root cause of much of the need to access the sub-structure at Teesside Offshore Wind Farm. Furthermore, the actions being carried out to manage H_2S at this site, such as improved CP, ventilation and monopile flushing, will require continued access to the sub-structure.



Management of H_2S Gas in Wind Turbine Sub-Structures

23rd May 2018 | Conaill Soraghan

CATAPULT Offshore Renewable Energy

Agenda

- Identification of H2S
- Root Cause Analysis
- Lessons Learned

ore.catapult.org.uk
@orecatapult
CATAPULT Offshore Renewable Energy

Identification of H2S Gas

Teesside Offshore Wind Farm

ore.catapult.org.uk
@orecatapult
CATAPULT Offshore Renewable Energy

Teesside Offshore Wind Farm

- **Owner Operator:** EDF-ER
- **Capacity:** 62.1MW
- **Number of Turbines:** 27
- **Manufacturer:** Siemens 2.3MW
- **Operates from:** Port of Hartlepool
- **Distance to Shore:** 1.5km

ore.catapult.org.uk
@orecatapult
CATAPULT Offshore Renewable Energy

Wind Farm Handover

Wind farm handed over to Operations in October 2013

- Known defects from construction:
  - Inadequate ventilation (inlet system not completed as per design)
  - 12 turbines with failed Tekmar seals
  - Davit cranes not commissioned
- First week of Operations
  - Reports of strange smells within the Wind Turbine and the transition piece
  - Instigated immediate investigation

ore.catapult.org.uk
@orecatapult
CATAPULT

Immediate Action

- One-week full site safety stand down was agreed to permit sufficient time for the operations team to carry out a full investigation
- All turbines inspected using a combination of personal and fixed gas monitors
- The investigation found small levels of Hydrogen Sulphide (H_2S) (< 5ppm) within the transition piece on some WTGs
- Safety briefs and tool box talks given to all technicians
- Equipped all staff with personal gas monitors

Zero tolerance on H_2S
- If any level of H_2S was detected the turbine was not to be entered and all works was suspended
- Ventilation system was then set up to allow entry into the turbine

ore.catapult.org.uk
@orecatapult
CATAPULT

Hydrogen Sulphide

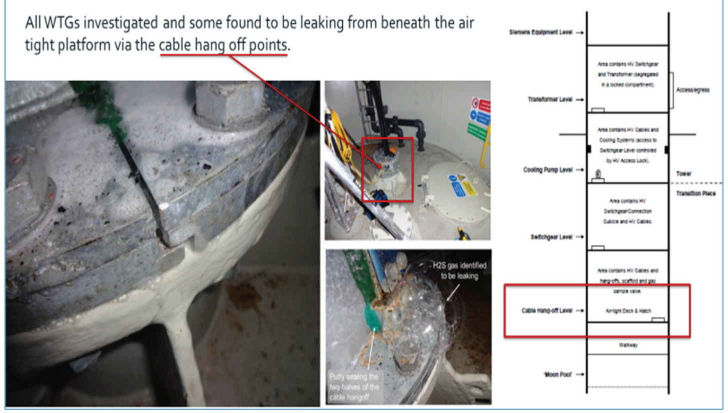
Hydrogen sulphide (H_2S)
- Colourless gas with the characteristic smell of rotten eggs at lower concentrations.
- Slightly denser, and therefore heavier, than air.
- Poisonous, corrosive, flammable and explosive at certain concentrations.
- Subject to the requirements of the COSHH Regulations.

Concentrations
- Low concentrations irritate the nose, throat and eyes while high concentrations can cause nausea, sickness and even death.
- The lethal dose for humans is 600 parts per million (ppm) for 30 minutes or 800ppm for five minutes.
- The Health and Safety Executive (HSE) has set the following Workplace Exposure Limits (WEL) for H_2S in EH40:
  - 5ppm for eight hours Long Term Exposure Limit
  - 10ppm for 15 minute Short Term Exposure Limit

ore.catapult.org.uk
@orecatapult
CATAPULT

Initial Findings

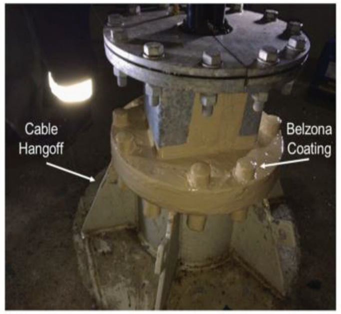
All WTGs investigated and some found to be leaking from beneath the air tight platform via the cable hang off points.



CATAPULT

Fixing the Leaks

- Initial coating test was carried out. Monitored over a 14 day period, no gas evident above air tight platform.
- Irrespective of any H2S readings all wind turbines sealed as a matter of precaution due to a potential future leak path.
- After application no further reports of H2S above the airtight deck have been recorded.



ore.catapult.org.uk
@orecatapult
CATAPULT

monopile (water ingress).

ore.catapult.org.uk
@orecatapult
CATAPULT

Root Cause Analysis

Teesside Offshore Wind Farm

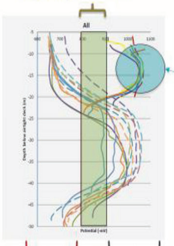
ore.catapult.org.uk
@orecatapult
CATAPULT

- Poor ventilation

ore.catapult.org.uk
@orecatapult
CATAPULT

CP performance

Electric potential measured at various depths from airtight deck:

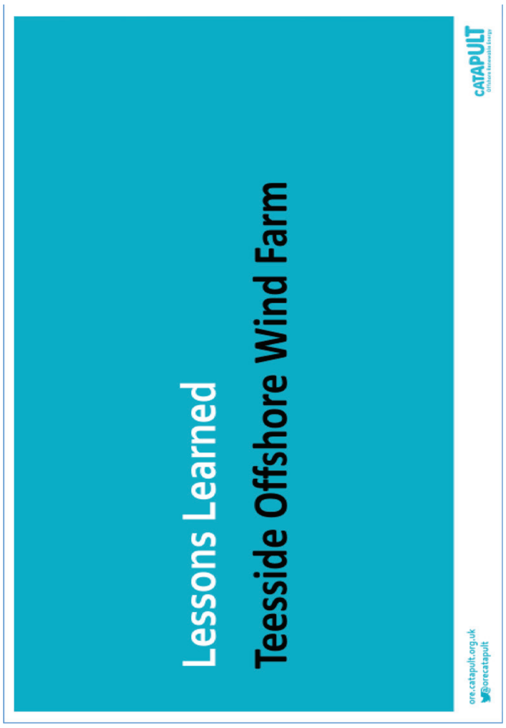


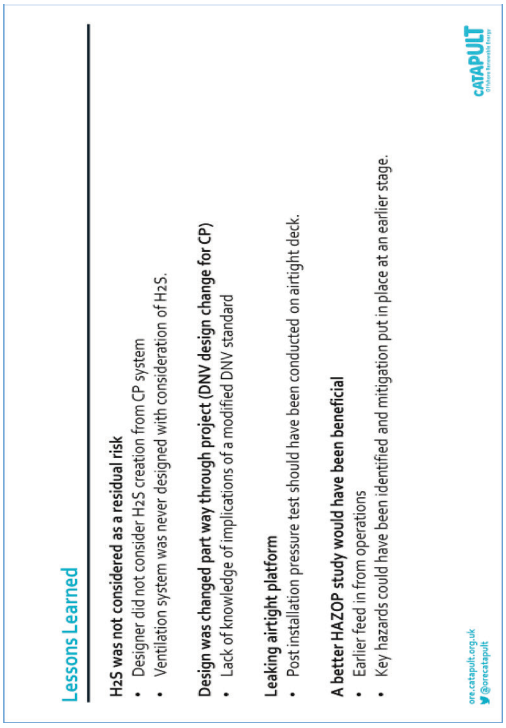
ore.catapult.org.uk
@orecatapult
CATAPULT

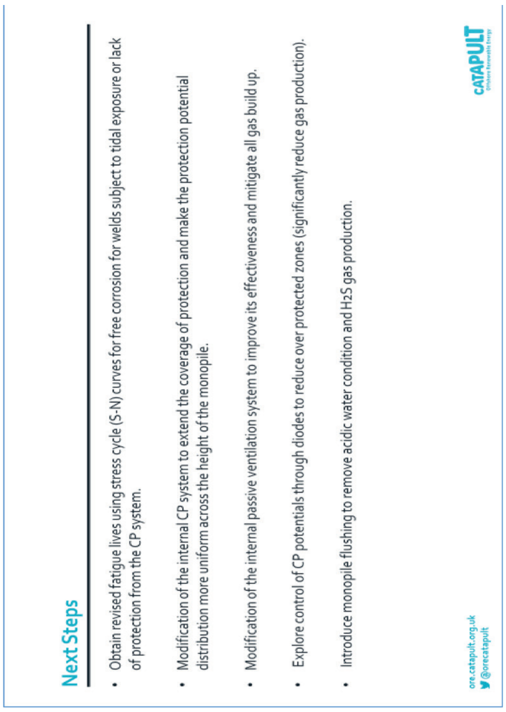
Ventilation

- Passive ventilation initially designed for Hydrogen (not H2S).
- The system incorporated two pipes passing through the airtight platform: An inlet pipe and an exhaust pipe.
- The inlet pipe should have incorporated a non return valve, however this was not designed or installed and H2S could potentially re-enter the TP.
- All inlet pipes were fitted with a shut off valve and permanently closed.
- Inlet now used to connect ventilation unit.

ore.catapult.org.uk
@orecatapult
CATAPULT


Lessons Learned
Teesside Offshore Wind Farm
ore.catapult.org.uk
@orecatapult
CATAPULT


Lessons Learned
H2S was not considered as a residual risk
• Designer did not consider H2S creation from CP system
• Ventilation system was never designed with consideration of H2S.
Design was changed part way through project (DNV design change for CP)
• Lack of knowledge of implications of a modified DNV standard
Leaking airtight platform
• Post installation pressure test should have been conducted on airtight deck.
A better HAZOP study would have been beneficial
• Earlier feed in from operations
• Key hazards could have been identified and mitigation put in place at an earlier stage.
ore.catapult.org.uk
@orecatapult
CATAPULT


Next Steps
• Obtain revised fatigue lives using stress cycle (S-N) curves for free corrosion for welds subject to tidal exposure or lack of protection from the CP system.
• Modification of the internal CP system to extend the coverage of protection and make the protection potential distribution more uniform across the height of the monopile.
• Modification of the internal passive ventilation system to improve its effectiveness and mitigate all gas build up.
• Explore control of CP potentials through diodes to reduce over protected zones (significantly reduce gas production).
• Introduce monopile flushing to remove acidic water condition and H2S gas production.
ore.catapult.org.uk
@orecatapult
CATAPULT


Contact us
GLASGOW
ORE Catapult
Inovo
121 George Street
Glasgow
G1 1RD
T +44 (0)333 004 1400
F +44 (0)333 004 1399
BLYTH
ORE Catapult
National Renewable
Energy Centre
Offshore House
Albert Street
Blyth, Northumberland
NE24 1LZ
T +44 (0)1670 359 555
F +44 (0)1670 359 666
LEVENMOUTH
ORE Catapult
Fife Renewables
Innovation Centre (FRIC)
Ajax Way
Leven
KY8 3RS
T +44 (0)1670 359 555
F +44 (0)1670 359 666
info@ore.catapult.org.uk
ore.catapult.org.uk
@orecatapult
CATAPULT

ANNEX C
ABBREVIATIONS AND ACRONYMS

CO	carbon monoxide
CO_2	carbon dioxide
CP	cathodic protection
EI	Energy Institute
G+	G+ Global Offshore Wind Health and Safety Organisation
HAZID	hazard identification study
H&S	health and safety
HSE	Health and Safety Executive
H_2S	hydrogen sulfide
NDT	non-destructive testing
OEM	original equipment manufacturer
O&M	operation and maintenance
PPE	personal protective equipment
RPE	respiratory protective equipment
ROV	remotely operated vehicle
SbD	Safe by Design
TP	transition piece
WTG	wind turbine generator

Energy Institute
61 New Cavendish Street
London W1G 7AR, UK

t: +44 (0) 20 7467 7100
e: pubs@energyinst.org
www.energyinst.org

9781787250215

ISBN 978 1 78725 021 5
Registered Charity Number: 1097899