WES Development Guidance – Lessons Learnt from Real Sea Deployments

Guidance on Installation

WES_KH03_ER_04

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Project Participants

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Glossary

AIS	Automatic Identification System. An electronic system installed on vessels above a minimum size that sends out and receives information of location, speed and vessel details.
ALARP	As Low As Reasonably Practicable
CAPEX	Capital Expenditure. “One off” costs for the design, procurement and fabrication of an item.
CDM	Construction (Design and Management) Regulations
CMS	Construction Method Statement
CoB	Centre of Buoyancy
CoG	Centre of Gravity
EIA	Environmental Impact Assessment
EMEC	European Marine Energy Centre
EMP	Environmental Monitoring Programme. The ongoing monitoring proposed and followed during the deployment of device and associated seabed assets.
EPS	European Protected Species
ERCoP	Emergency Response Cooperation Plan. An official plan from the MCA.
ERP	Emergency Response Plan
FAT	Factory Acceptance Test
FMEA	Failure Mode and Effect Analysis
HIRA	Hazard Identification and Risk Assessment
HV	High Voltage. Currents over 1000V AC.
IMS	Integrated Management Systems. Sometimes referred to as a Safety Management System or an Integrated Safety Management System.
LAT	Lowest Astronomical Tide
LCOE	Levelised Cost of Energy. A means of comparing the cost of energy between different sources that includes all capital costs, operational costs, depreciation, costs of borrowing money etc.
MCA	Maritime Coastal Agency
MS-LOT	Marine Scotland Licencing and Operations Team. As Scottish Ministers are the licensing authority for most matters in Scottish inshore and offshore waters, MS-LOT are a team within Marine Scotland that issue marine licences on behalf of Scottish Ministers. MS-LOT provide a ‘one-stop-shop’ for all marine licence applications and Section 36 consents in Scottish waters.

NRA	Navigation Risk Assessment. A judgement of how much risk the device will pose to other maritime users, both in service and in the case of failure.
O&M	Operations and Maintenance
OPEX	Operational Expenditure
OSC	Orkney Supply Chain
PA	Local Planning Authority. Usually associated with any onshore works and permissions.
PPE	Personal Protective Equipment
PR	Public Relations
ROV	Remotely Operated Vehicles
STCW	The International Convention on Standards of Training, Certification and Watch Keeping for Seafarers specifies the minimum standards for training and qualification for those working at sea.
TPV	Third Party Verification
TRL	Technology Readiness Level
USBL	Ultra-Sonic Baseline. A method of underwater position measurement using acoustics.
WEC	Wave Energy Converter
WES	Wave Energy Scotland
WES Stages	A series of defined steps along a technology's progression through the WES programme.

Executive Summary

To inform developers within the programme and to minimise the risk of having to relearn past lessons, Wave Energy Scotland has commissioned a number of projects to capture industry Know-How. This document is part of the third Know-How project, which aims to produce a set of guidance documents that draw on the lessons learnt from real sea deployments at EMEC. The guidance documents are underpinned by the deployment experience built over the last 12 years within the Orkney Supply Chain (OSC). The input to development of these guidance documents is unprejudiced in drawing together both the positive and negative lessons learnt and cover a depth of expertise captured within each of the participating supply chain companies.

This guidance document highlights the issues to be considered under the theme of installations and most specifically the planning, resources and impacts vessels, people and the design have on the installation of the WEC, the moorings and/or foundations. The discussion with the OSC around installation challenges was focused on the importance of effective planning, peer review and design. The below sections underpin these discussions and the checklists created.

The main requirements covered under installation are:

- Installation Planning
- Onshore and Offshore Installation activities
- Device / Connections / Moorings considerations

The basic concepts of the installation should be investigated in concept development during WES Stages 1 and 2 and, as the design becomes more certain and the site for Stage 3 deployment becomes apparent, review of installation methods and development of procedures should take place using a HIRA with all participants providing feedback.

There are other industry guidelines covering aspects of installation[1], this report, based on the lessons learnt from the OSC, should complement these other guidelines.

The blue highlighted boxes in the report sections are there to question the developer team to ensure awareness, planning, engagement and implementation of the critical, high level checklist items. Where appropriate they are referenced back to the checklist.

Following the Installation document are segregated checklist proformas relevant under the installation theme. The guidance documents covering Compliance, Handling and O&M[2] have synergies with the installation theme and cover in detail issues such as planning and H&S.

[1] EMEC recommends the MERiFIC Best practice report – Installation Procedures March 2014 http://www.merific.eu/files/2012/06/D3-6-2-FINAL-Best-Practice-Report_Installation_Procedures.pdf

[2] WES_KH03_ER_02 – Guidance on Compliance; WES_KH03_ER_03 – Guidance on Handling; and WES_KH03_ER_05 – Guidance on Operations and Maintenance.

1 Introduction

The potential for job creation and internationalisation in the wave energy sector is considerable. The theoretical wave resource available to the UK alone is estimated to be up to 27 gigawatts (GW)[3] of recoverable energy, with the opportunities for R&D immense. The European Marine Energy Centre (EMEC) in Orkney has hosted the majority of the world's wave and tidal sector prototype testing. However, challenges to the wave development trajectory in terms of device survivability, reliability and performance, including cost effective installation, recovery, operations and decommissioning works have undermined the successful development of the wave energy sector. With the formation of Wave Energy Scotland (WES) in 2014, the aim has been to bring a measured and phased approach to technology development to address these challenges. The phased approach is now established in the stage-gated WES Innovation Pathway programme. Novel Wave Energy Converters, PTO developers, material specialists, subsystem and component innovations passing through the WES programme will be thoroughly analysed and tested ensuring the wave sector is prepared and ready prior to large scale prototype deployments in the sea. An example of a typical table of stage activities is given in Appendix A:

This WES commissioned guidance document has been produced to capture the knowledge and lessons learnt by the Orkney Supply Chain (OSC) during the last 12 years. The contributing companies comprised a range of expertise encompassing environmental, electrical, marine operations management, diving and vessel hire companies, and include Aquatera, Bryan J Rendall Electrical, EMEC, Green Marine, Leask Marine, Offshore Subsea Consultancy Services, Orcades Marine, Scotmarine, Sula Marine and the Xodus Group. The guidance documents demonstrate the approach taken in capturing this wealth of knowledge without jeopardising the inherent intellectual property of any individual supply chain company.

Four major themes have been considered as part of this project, and each is explored in detail in its own report delivered as part of this project;

- WES_KH03_ER_02 – Guidance on Compliance
- WES_KH03_ER_03 – Guidance on Handling
- WES_KH03_ER_04 – Guidance on Installation
- WES_KH03_ER_05 – Guidance on Operations and Maintenance.

This guidance document focuses on the theme Installation. A description is provided separately[4] describing how the project was brought together, how feedback was discussed, and how the priority lessons learnt were captured. Details of participating companies are also given in this overview.

Installation is a very specific part of the device development program where the equipment supporting the open water testing of the device is deployed at sea and commissioned. The action of installation is specific to Stage 3, as prior to this all testing is done in controlled test tank conditions. However, preparation and risk mitigation will be covered within Stage 2 activities.

Depending on the type of device, installation can include the deployment of permanent moorings, the installation of shore based power conditioning equipment or even the permanent deployment of the device or subsystem onto a fixed seabed foundation. The specialist tasks undertaken here are often outside the skillset and experience of a developer,

[3] As outlined in The Crown Estate's UK Wave and Tidal Key Resource Areas Project Summary Report, available here: https://www.thecrownestate.co.uk/media/5476/uk-wave-and-tidal-key-resource-areas-project.pdf. This report described the findings from a study undertaken to produce a consolidated view of wave, tidal stream and tidal range resources and make improvements in spatial analysis to help determine the geographic distribution of resources.

[4] WES_KH03_ER_01 – Approach and Supply Chain

and require involvement of the supporting supply chain. The temptation to assign these tasks to internal resources with little or no experience of operating in open water environments should be resisted, as this has time and again proven to be a false economy with significant cost increases later due to inappropriate or inefficient approaches being used.

As the industry matures, with the installation of multiple devices, the methods learnt at single device installation will inform the future array scale deployments. Multiple vessel operations will increase OPEX costs; therefore, it is critical deployments are well planned and monitored for continuous learning at the earliest stages.

The following sections are not exhaustive in terms of all regulatory, standard or best practices for the installation of WEC devices and subsystems. This document only includes items that were flagged as particularly pertinent issues with the OSC. Where possible, these have been described in detail in terms of the project-based requirements, and to ensure that challenges encountered previously have the best opportunity of being avoided in the future. The document should be used as guidance only. It should be noted that information and guidance provided within this document is appropriate at time of writing but is liable to change with regulations and legislation being updated. Developers should consult with experienced local marine contractors, engineering/environmental consultants and/or the test site management to ensure that the installation activities they propose to implement are fully compliant with relevant regulations and legislations for the site location.

This suite of guidance documents should be used interactively and as an aid in providing a framework for engagement between developers and the supply chain during the planning and implementing of large-scale testing.

2 Requirements

2.1 Installation Plan

Planning is covered in detail under the guidance for Compliance and O&M. It is recommended that the installation plans are developed with the advice and support of marine contractors local to the deployment site, who have the onsite experience as well as understanding of the requirements for the safe securing and connecting of marine energy devices. Vital to informing the best installation methodologies will be their involvement in the technology risk assessments. Prior to the installation, inspections of the device and subsystem are recommended by the marine contractors to ensure safe installation.

As with all significant onshore and offshore operations, a detailed procedure with contingencies and an emergency response plan in place is advised. Given the scale of the installation operations, and their unique nature, there will be a requirement for a group review of the draft procedure and incumbent risks for health and safety purposes. This is done in the format of a HIRA, where risks are identified and a means of mitigation is proposed. The draft procedure then gets updated and issued to relevant stakeholders involved or made aware of the installation operations. It is important to include all contractors in the HIRA that will contribute towards the operation as they will all have their viewpoints and experiences to contribute toward the review, and to ensure they have a full appreciation of the complete operation.

Have you ensured your installation plan has been peer reviewed? (Stage 2)

2.2 Risk Management

Installation methodologies have not been standardised as yet due to the variety of different WEC designs still under investigation. It is therefore important to ensure a robust approach to health and safety through risk management. It is considered essential that marine operations, including all support activities, are thoroughly assessed at the conceptual design stages to determine if a concept can be safely installed with no or low risk to the environment. Identifying risk through HIRA's includes low and high risk identification. For example, a low risk installation of a low weight device that can be efficiently towed to site, thereby improving OPEX costs. However, there are still negative risks associated with a low weight device if the CoG or ballast behaviour is not well understood. Incorporating risk management and quality assurance processes will be a positive influence, rather than a restrictive constraint on progress through your technology development programme.

Risk management should address redundancy and backup philosophies as well as all other activities required to reach an acceptable risk level. It should assess risk exposure to personnel and possibilities for reducing this exposure through use of remotely operated tools and handling systems.

Risk management tools such as the HIRA process are used to optimise operations and reduce the inherent risks of working at sea. Marine hazards are diverse in nature, and can be quite different from land based risks that engineers are commonly more used to. They include:

- Loss of station keeping (e.g. mooring);
- Loss of structural integrity (e.g. hull, support structure failure);
- Loss of stability (e.g. ballast system failure);
- Collision (e.g. support vessel, passing vessel).

Metocean conditions have the greatest impact on installations in terms of installation times (weather windows) and ability to secure and connect the marine energy device. O&M

planning tools will help to mitigate risks, however ultimately it is the experience of the marine contractor, vessel captain and crew that should prevail during installation operations.

2.3 Environmental Conditions

At the point where a test site for Stage 3 is known, there are environmental factors that can influence installation. These include the seasonal variation in wave and wind conditions, both in intensity, and also in predominant direction with regards to the exposed open sea and the protected shore. Historic records can identify which weather patterns found at certain times of year are favourable to installation, and can assist in detailing the bounds of working conditions at a specific site.

Wave energy developers often neglect the impact of tidal flow on test sites. There is often a noticeable effect on operations, especially when the tidal flow is against the wind/wave direction and produces unfavourable installation conditions. Tidal charts can give an estimation of the flows involved, but local marine contractors will be able to give definitive accounts of how it may impact operations. On site measurements may also prove beneficial and pre-installation environmental surveys should be arranged if no prior existing installations have occurred.

There are O&M planning tools in existence and in development[5] that take hindcast data along with detailed site data and combine these with quality controlled forecasts to provide both a mission success chance, but also often ways of optimising operations within the expected weather windows. These tools are in the early stages of their development, but promise to offer a significant input into the risk management of operations from both a H&S point of view and an economic optimisation point of view.

An often-neglected requirement during installation planning is the welfare and human logistic needs of all involved, which is acutely important at remote sites. Therefore, it is important to be aware of these needs at Stage 3 and start to plan for welfare needs and the working environment. For example, travel to quayside or adequate facilities at site during down times/rest times.

Have you evaluated or considered an O&M planning tool for supporting your operations? (Pre WES and Stage 1)

2.4 Personnel

As with the more regular O&M activities that follow, the tasks carried out during installation need some very specific skills and experience which few developers will have ‘in house’. Sourcing guidance and advice from marine contractors/consultants or other competent persons is recommended where a developer may not have developed this experience internally. Sourcing guidance and advice from marine contractors/consultants or other competent persons is a suggestion primarily aimed at developers who have not had the opportunity to develop this experience themselves to date. The building of these skills and experience internally within the device development company will occur over time if they choose to be involved with the operations, rather than contracting the complete operation out. Retaining experience and expertise of this in-house is invaluable for future design and development work

In order to ensure that personnel working offshore are suitably trained, competent and qualified to work safely offshore, certain training requirements need to be fulfilled. There are a number of training providers and qualifications available to ensure that all of those working

[5] Examples of O&M planning tools available include: Forecoast Marine from JBA Consulting (http://www.forecoastmarine.com/), and Mermaid from Mojo Maritime (http://mojomermaid.com/)

offshore are suitable trained. A common training and certification in this area is the International Convention on Standards of Training, Certification and Watchkeeping for Seafarers (or STCW) Basic Safety Training course (STCW95 & STCW 2010) which is the legal minimum requirement for anyone looking for commercial work aboard vessels over 24 metres, in accordance with the STCW Code A-VI/1. There are other training and certification packages available, such as BOSIET. Renewable UK has provided guidance as to which courses are best suited for which environment[6]. Developers must confirm themselves which legal requirements are necessary for the work they are proposing to conduct.

Successful completion of STCW95 & STCW 2010 training courses requires personnel to demonstrate, to the required level, theoretical understanding and knowledge, and practical application of safety at sea skills. The following elements of training and assessment are normally undertaken as a requirement:

- Continuous development and skills enhancement, ensuring that the competency standards are maintained and developed, accounting for new and changing health and safety hazards and risks;
- Refresher training & assessment taking place on a regular basis to ensure basic skills and knowledge level is maintained.

Have you developed a capabilities matrix to inform gaps in personnel skills or training needs? (Stage 1)

2.5 Onshore Infrastructure

The installation of equipment in Stage 3 will be the first exposure to the local infrastructure, such as the local road network, grid strength and availability and support services provided by local companies. It will also likely be the first time a developer is closest to the limits of road capacity, ferry capacity, lifting capacity and vessel capacity available locally. Remote sites may have narrow, light duty roads that need traffic management plans in place for the movement of heavy loads, such as containers with power conditioning equipment, or gravity based mooring components. Experience haulage companies familiar with the challenges presented should be involved in order to mitigate against unexpected and expensive re-working of plans. An understanding of the site is beneficial at Stage 2, while requirement for welfare needs and human logistics should be planned for at Stage 3.

As detailed in the handling guidelines, determining local capacity in terms of shore based lifting, handling, and storage along with vessel lifting, winching, towing and cargo transport will be key when developing installation plans. An early identification of pinch points can allow for cost effective, timely modification and re-working.

Consideration should be devoted to understanding if onshore electrical test facilities are required to support offshore testing of the device.

Have you visited the site to understand the onshore requirements for facilities, routes and supplies to support installation activities? (Stage 2)

[6] Offshore Wind and Marine Energy Health and Safety Guidelines 2014: Issue 2

2.6 Offshore

2.6.1 Offshore renewable energy installations: impact on shipping

The Maritime and Coastguard Agency (MCA) has released updates to a guide on the impact on shipping from offshore renewable energy installations (OREIs).

Due to locations, size and deployment areas of OREI's, there are challenges to the safe navigation and communication of shipping and emergency rescue. The newly updated guide (December 2016) should be referenced in full for developers seeking consent for marine works, as the recommendations from MCA if not taken into consideration, will entail delays to formal consent. The recommendations[7] define how developers should address the navigational impacts and emergency response plans to be in place at the OREI sites.

2.6.2 Vessels

Vessel selection is covered in detail under guidance for O&M. However, given the one-off unique nature of the installation operations and the potential difference in scale of moorings/foundations etc., it is not unusual for developers to charter a larger scale vessel that may appear better suited for the task at hand. A warning when using this approach is that these vessels may have reduced understanding of local conditions and restrictions. Contracting a marine consultant with experience of the specific site conditions to oversee the operations is one way to reduce the likelihood of costly mistakes.

Examples of offshore vessels used for installation at the EMEC sites have covered:

- Multicats
- Gantry Barge
- Tugs
- Jack-up barge
- Heavy Lift Vessels

If intending to keep all marine operations within the readily available and cost effective equipment capabilities of a local marine contractor, then it is again important to scope all activities well in advance of final detailed design to ensure this equipment has sufficient capacity. As an example of the cost reductions that may be possible, the Orkney Vessel Trials, completed in 2013/14 and utilising 20 local organisations, demonstrated that developers could save up to 70-80% on installation costs by utilising a gantry barge and other local vessels rather than commissioning large dynamically positioned offshore construction vessels.

Have you developed, as part of your operations plan, detailed equipment requirements referenced to specific onshore and offshore activities? (Stage 1)

2.6.3 Communications

The importance of robust and redundant communications is covered in guidance for O&M and Compliance, and should be referred to. In terms of installations the wave test sites are often found in the remoter parts of the world, and as such do not always enjoy high standards of telecommunication. Assumptions of good phone signal and mobile internet are flawed, and potentially dangerous where these technologies are built into emergency procedures. VHF, UHF and satellite phone communications provide options of varying security and cost which can allow for backup communications to be in place for operational, critical and emergency situations.

[7] Safety of Navigation: OREIs – Guidance on UK Navigational Practice, Safety and Emergency Response
https://www.gov.uk/guidance/offshore-renewable-energy-installations-impact-on-shipping

During pre-commercial testing, an approach of assuming little to no communication with shore can save on the time spent trying to establish communication in a poor reception zone. Effective planning can ensure that most, if not all, data required during an operation is captured within the physical documentation, or contained in an offline computer on the vessel. An exception to this observation is during the completion of electrical, fibre optic or hydraulic work requiring actions onshore and offshore. Solid communications need to be set up and tested to ensure that clear communication of actions and permit states are reported and acknowledged between parties.

2.7 Device Design

The HIRA for the installation procedure requires the design of device or component to be finalised. This is occasionally overlooked as designs continue to be refined up to the last minute, which can have significant negative impacts on the ease of installation, and on safety factors of pre-installed equipment, such as moorings. If changes are made then a HIRA is required based on the changes and the impact to the installation operations. As investigated in the device system, subsystem and component FMEA, any changes to the structural elements added under an FMEA should take into consideration the corrosion or biofouling effects on structural loadings, for example. Components are often not fully protected during assembly and installation and most failures can be avoided if properly secured, for example umbilical cables.

It is important to adhere to the change management procedures for any design changes and to communicate these changes accordingly to all stakeholders from manufacturer to the marine contractor who will lift and install the device. The importance of updating and documenting the changes to the design and engineering drawings will provide ease of documenting and recording any failed components if they occur.

At Stage 3 the 'as built' report should be made available to the marine contractors for review in determining best installation method for the respective device. Frequently marine contractors have not had access to the 'as built' design and after device delivery to site and after visual inspections have noticed the lack of or incorrect specification of lifting points. These design mistakes have delayed deployment timelines.

Have you demonstrated an understanding of the impact design changes to any device, subsystem or component have on all handling, installation, operations, maintenance, recovery and decommissioning activities? (Stage 2 and 3)

2.8 Connections, Moorings and Foundations

When designing electrical connections and moorings, consideration should be given to their safe and practical installation and access for maintenance. At the WES Stage 1 conceptual design phase it is recommended that the designer creates a high-level overview of the cabling, moorings and/or foundation configurations for the device. The cost and time associated with complex installations for connections and moorings systems can be avoided, by engaging with a marine contractor following completion of concept design.

At WES Stage 3 it is recommended to do FMEA and develop a predictive maintenance programme for the device subsystems, and that mooring construction, assembly and testing takes place onshore as far as possible. As discussed in the compliance guidance, TPV of the subsystems should be carried out and certified prior to installations.

In terms of connections it is recommended to optimise and document a quick connection and disconnection plan as part of operational planning. As discussed in the O&M guidance, the importance of ensuring the structural and mechanical protection of electrical connection systems should be in place prior to installation.

Have site specific considerations been taken into account on the connections, moorings and foundations design? (Stage 3)

2.9 Installation Inspection

Prior to the installation of any assets on the seabed, a complete survey will have been undertaken in compliance with a marine licence condition. This confirms the seabed condition as a baseline to compare against once decommissioning has been completed.

On the hire of vessels and their operators it is recommended to complete an inspection, especially for single hires of non-local vessels, as there may not be appropriate vessels to work alongside or part of multi-vessel operations. They could have inadequate communications systems or safety equipment on-board.

At Stage 2, preparation of the factory acceptance test (FAT) for the commissioning of the Stage 3 device is recommended. Once installation activities start there is a duty of client representation to be considered. For example, a safety officer or observer may be required to be present during the operations, and this will depend on the type of activities being completed. While there are independent, certified professionals available to carry out this task, it is suggested that the developer should also put staff on board the vessel to observe and learn where the operation runs smoothly, and where it needs adaptation. This staff member must have the minimum required training to work on the vessel, and should ideally have some experience of working at sea, so they can contribute as required/instructed to form valid conclusions from their observations. This is an important feedback loop for lessons learnt and installation procedures, method statements should be updated accordingly.

Do you have a phased approach to inspections concluding each Stage and or development phase? (Stage 1)

2.10 Installation Recording

It is recognised that often procedures do not go exactly as planned, which can often add risk to subsequent operations. In either case, there is value in recording the events as they happen. As-laid survey reports for seabed assets are invaluable later in operations as they can define the exact layout of cables, chains, anchors and other mooring components. These can change by tens of metres from the documented intended locations. Often, this has no significant impact other than difficulty of finding them later but unless it is recorded, the risk from assuming its location will remain. Having a detailed chart showing the exact as left/as laid locations of all seabed assets is very valuable to developers and marine contractors who often need to find clear seabed to place temporary moorings. Poor survey and maintenance of records can lead to incidental damages. It is also important to re-run device simulations/calculations to ensure that the dynamics and structural loads are not adversely affected by misplaced anchors, for example.

Recording deviations from the planned activities is of value in terms of adjusting future procedures, or for re-evaluating the capabilities of vessels, contractors and equipment.

2.11 Decommissioning

Decommissioning is discussed in the compliance guidance and should be referred to in terms of the regulatory requirements. The decommissioning phase of the technology programme is often overlooked in terms of budget and planning. Marine Scotland's requirement is to plan and budget for the decommissioning programme, taking into consideration the need to have a separate marine licence for removal. As with operational planning, decommissioning will involve the same inherent hazards and risks, and thus should be identified in the technology risk register and output into the relevant method statements.

Excellent planning, communication and co-ordination during decommissioning will mitigate safety risks. Recovery risks identified within the OSC workshops, were on the additional mass added to the WEC, its moorings and or foundations due to biofouling growth, and the possible deterioration/damage to lifting points. All risks associated with decommissioning should be taken into consideration in terms of offsetting weight distributions and the planning of recovery activities.

The weather working limits will once again be a complex combination of wind, wave and tidal velocities, along with the working limits set for any crane, towing or diving operations. As recommended in the handling guidance, an O&M tool for planning decommissioning activities should be utilised.

3 Conclusion

In summary, the requirements for installation cover many of the same threads (risk management, environmental/site conditions, planning) under discussion in the handling and O&M guidance documents. The OSC focused their discussions on lessons learnt covering issues such as delays to installation or recovery works due to vessel availability, poor communications or lack of adequate resources onshore. Design changes following HIRAs have been a considerable issue at the EMEC site, and should be avoided prior to WES Stage 3 testing. There are also specific challenges around the electrical connections and cable installation activities and the most missed topic of decommissioning the device which in principle is a reverse installation activity, but with its own associated impacts on the WEC and subsystems. The recommendations from OSC is early engagement with marine contractors and peer review at design stages which can significantly mitigate the risk of late design modifications, and lead to reduced installation and recovery costs.

Following are the installation checklist proformas. It is important to note the checklists are categorised under the respective WES Stage (Pre-WES, Stage 1, Stage 2, Stage 3) based on the following guidelines for relevance. At the appropriate stage the developer should have:

- Pre-WES – Gain an awareness of checklist item. Understanding differences in requirements between sites.
- Stage 1 – Plan for addressing checklist item, taking into consideration statutory timescales/requirements where necessary. Be aware of design modifications that may be required in following stages, mitigate where appropriate.
- Stage 2 – Engage/collaborate/analysis during scale tank testing to mitigate/address checklist item. Begin preparing required plans ready for completion/submission and implementation in Stage 3. Ensure plans are in line with available standards, guidance documents and best practice.
- Stage 3 – Implement checklist item in onshore/offshore activities. Record any lessons learnt and opportunities for future testing, disseminate findings for industry-wide learning.

3.1 Checklist Definitions

The Checklist threads below in Table 2 are the priority checklist items covered in detail with the Orkney Supply Chain (OSC) and prioritised under the compliance guidance. The OSC agreed on specific definitions for each thread for clarity. The proformas should be used interactively and provide a framework for further discussion ahead of future activities.

Table 1. Checklist definitions

Thread	Definition
Operations planning	Ensuring that each operational stage, whether in a laboratory, factory, on land or at sea, is effectively planned and executed.
Contingency arrangements	Suitable plans and related arrangements are in place to implement if and when things change or don't go as planned.
Device Structure	Ensuring that there is appropriate integrity within the structure of the device for all stages of handling and deployment and that this integrity is monitored during device deployment
Connections and Moorings	Ensuring that these enabling technologies are fit for purpose, use proven solutions where possible and build upon local site capacity.

Thread	Definition
Inspection and Monitoring	Ensuring that suitable means for inspection and monitoring have been considered and put in place covering integrity, performance, environmental interactions, safety etc.

Appendix A: WES Development Pathway and Checklist Proformas

Throughout the development workshops the documenting of supply chain issues and recommendations was carried out using proformas. The workshops were designed to build the proformas and indicate which specific topic and associated issues were important to address at which Stage.

An indication of the topics that should be considered at each Stage of the WES NWEC Programme has been provided below. In addition, a high level overview of the pre-WES requirements is also included. It is understood that each of the WES programmes will have a variation of these typical activities, dependent on the system development programme and the most appropriate stage gated progression. The checklist proformas for each of the prioritised OSC threads relevant to installation follow this.

Pre WES Concept Creation Feasibility Work	**WES Stage 1** Concept Characterisation & Refinement	**WES Stage 2** Concept Optimisation & Demonstration of Engineering Specification	**WES Stage 3** Small Prototype Development
• Basic technology research • Technology concept formulated • Geometry • Hydrodynamics • Numerical modelling • Natural period • Weight distribution • Small scale tests	• Concept development • Systems engineering • Numerical model and simulation • Power performance estimates • Device efficiency • Shape optimisation • Scale model / component testing	• Concept refinement • Technology optimisation • Control system design • FEED study • Large scale tank testing • Numerical model validation • LCOE calculation • CAPEX estimation • Subsystem testing	• Refined system • Design and fabrication understood • Large open water model developed • Fully operational system • Performance proven for full system • Certification of system

Operations planning	Aim: Ensuring that each operational stage, whether in a laboratory, factory, on land or at sea, is effectively planned and executed.

This involves implementing the WES staged approach to system design. The staged system design plan will fundamentally inform the operational planning phases at WES Stage 1 & 2 based on the system, subsystem and component size, weight, layout, interfacing and handling of the device.

At the early stages, it is essential to begin to understand how the device will be deployed and make the necessary design decisions to ensure that it will be an effective and simple operation. Early engagement with the supply chain will bring intangible benefits to the design process, particularly where they may be experienced with the site conditions and understanding of the resources/equipment available. Once the necessary operational plans have been developed for installation, handling, O&M and decommissioning, it is essential to storyboard these with the marine contractor to identify possible risks and issues.

Operational plans remain live documents which are continually updated to reflect current practices and lessons learnt. As the operational plans are updated with more detail, it is necessary to review the strategic programme plans in light of changes and ensure there is a feedback loop. HIRA workshops should be conducted with both marine and onshore contractors present to ensure there is continuity in the planned works, the results will inform the operational method statements. Clear and concise method statements including contingency plans should be discussed at the tool-box talks. To accelerate the learning process, it is recommended to utilise external expertise and modelling tools, particularly regarding site conditions and limitations. The practicalities of decommissioning should be considered prior to installation to fully understand the requirements for such an operation.

Pre WES	WES Stage 1	WES Stage 2	WES Stage 3
☐ Gain an awareness of typical operational methods. ☐ Be aware of potential deployment site conditions and impacts to technology programme.	☐ Produce and implement method statement / operational plans for any Stage 1 testing. Refer to existing methods and standards where available. ☐ Develop and maintain operational plans for testing in WES Stage 2 and 3.	☐ Evaluate site needs and select appropriate sites(s) for further planning. ☐ Lessons learnt during Stage 1 testing reviewed and incorporated into appropriate Stage 2 and 3 plans. ☐ Hold an initial HIRA workshop, supported by appropriate storyboarding for installation and handling activities, develop prospective schedules with appropriate onshore and marine contractors. ☐ Ensure onshore space requirements (temporary and permanent) and leasing requirements are planned for.	☐ Update, review and refine the HIRA report from stage 2. Implement HIRA findings within operations. ☐ Finalise storyboard for Installation, Lifting and Handling, O+M and Decommissioning ☐ Ensure that suitable onshore facilities for testing and welfare are in place. Create safe zones around onshore equipment to prevent accidents. ☐ Ensure smooth handover of the device from the fabrication contractors to the test support contractors with sufficient documentation and FATs. ☐ Develop a traffic management plan, mitigation measures and contingencies if large loads are to be transported to and from site. Engage closely with the local planning authority to understand if there is a statutory requirement for a traffic management plan. ☐ Include a tow plan in the installation plan. ☐ Plan Tool Box meetings before each operation, both onshore and offshore.

			☐ Use third party peer review as a quality control step of method statements.

Relevant Industry Standards, Guidelines
EMEC Guidelines for manufacturing, assembly and testing of marine energy converter systems http://www.emec.org.uk/guidelines-for-manufacturing-assembly-and-testing-of-marine-energy-conversion-systems/ Carbon Trust guidelines on design and operations of wave energy converters http://www.gl-group.com/pdf/WECguideline_tcm4-270406.pdf DNV Marine Operations, General, DNV-OS-H101, 2011. https://rules.dnvgl.com/docs/pdf/DNV/codes/docs/2011-10/Os-H101.pdf

<table>
<tr><td>Contingency arrangements</td><td colspan="3">Aim: Suitable plans and related arrangements are in place to implement if and when things change or don’t go as planned.</td></tr>
<tr><td colspan="4">Contingency is a more important concept than many previous developers have grasped due to the remote nature of the test areas, plus the difficulty of accessing a device once deployed. Marine operations are one of the major costs in a test schedule, so implementing engineering contingency/redundancy can offer considerable savings. Delays in procurement both due to bespoke components and delivery times to remote location can impact test schedules, so an approach of FMEA followed by strategic spares procurement is advised. Consider merits of saltwater scale testing to allow for early identification of materials issues. Have contracts detailing day rates and contingency method statements in place for all marine activities. If ERP requires use of/ interaction with bespoke equipment, consider providing familiarisation with key contractors. Show consideration of recovery of components that may separate from device during failure event. Put contingency into communication plans. Another aspect of contingency planning is how to manage changes to the programme with your funders.</td></tr>
<tr><td>Pre WES</td><td>WES Stage 1</td><td>WES Stage 2</td><td>WES Stage 3</td></tr>
<tr><td></td><td>☐ Identify and develop operational contingency plans. Plan B's.</td><td>☐ Carry out FMEA for Stage 3 device, create spare parts inventory strategy to reduce delays in testing.
☐ Build requirement for Emergency Response Plan (ERP) for Stage 3 in sea testing into budgets, and start contractual negotiations with likely contractors.</td><td>☐ Ensure contract is in place to cover contingency and emergency plans.
☐ Consider how advanced warning of the potential failures might be modelled or measured for components.
☐ Hold adequate component spares in Inventory.</td></tr>
<tr><td colspan="4">Relevant Industry Standards, Guidelines</td></tr>
<tr><td colspan="4">Project Management Institute www.pmi.org Standard for Program Management – 3rd Edition.</td></tr>
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<table>
<tr><td>Device structure</td><td colspan="3">Aim: Ensuring that there is appropriate integrity within the structure of the device for all stages of handling and deployment and that this integrity is monitored during device deployment.</td></tr>
<tr><td colspan="4">In the concept phase, explanation of how structural integrity has been considered within the concept for the device and its related support subsystems, keeping in mind through preliminary analysis how structural integrity is achieved and maintained through the technology lifecycle and taking into account the basis of design and the related range of site conditions the device will encounter. Through Stage 2 and Stage 3 the engagement with operational experts to support validation of device integrity informed by test results and analysis is vital. Development of an integrity monitoring plan will improve overall health of device and subsystems from installation to decommissioning.</td></tr>
<tr><td>Pre WES</td><td>WES Stage 1</td><td>WES Stage 2</td><td>WES Stage 3</td></tr>
<tr><td>☐ Awareness of the importance of appropriate structural integrity within the concept feasibility work.</td><td>☐ Show through preliminary analysis how structural integrity is achieved and maintained.
☐ Gain understanding of device structural interface to distribution cable and its moorings/foundation configuration.</td><td>☐ Validate the integrity of the device with test results and updated analysis.
☐ Plan for what marine maintenance and work will need to be done subsea and send plan for dive/ROV provider reviews.
☐ Fully consider structural dynamics, fatigue and wear based upon real conditions and associated load patterns/cycles during design.
☐ Document anticipated material and component specifications.
☐ Plan for marine wet testing specific components and subsystems individually before incorporating into the overall device.
☐ Materials chosen should be evaluated against corrosion, or other mechanical/structural failure of device.</td><td>☐ Ensure that changes to structural elements and added components don’t compromise the corrosion or biofouling of structural loading design.
☐ ‘As Built’ report compiled and reviewed with local contractors.</td></tr>
<tr><td colspan="4">Relevant Industry Standards, Guidelines</td></tr>
<tr><td colspan="4">EMEC Guidelines for design basis of marine energy conversion systems. http://www.emec.org.uk/guidelines-for-design-basis-of-marine-energy-conversion-systems/
EMEC Guidelines for manufacturing, assembly, and testing of marine energy conversion systems. http://www.emec.org.uk/guidelines-for-manufacturing-assembly-and-testing-of-marine-energy-conversion-systems/
EMEC Guidelines for reliability, maintainability and survivability of marine energy conversion systems, 2009. http://www.emec.org.uk/guidelines-for-reliability-maintainability-and-survivability-of-marine-energy-conversion-systems/
LOLER regulations 1998.</td></tr>
</table>

Connections, moorings and foundations	Aim: Ensuring that these enabling technologies are fit for purpose, use proven solutions where possible and address local site capacity**.**

The physical reaction between a device and its moorings should be considered as part of the conceptual development. It's important to remember that most wave sites will also have a degree of tidal action, which adds considerable loads to a mooring system, and may well influence the natural rhythms and dynamics of a device in operation. Fully consider structural dynamics, fatigue and wear based upon real conditions and associated load patterns/cycles during design. Consider local advice regarding mooring configurations alongside modelled system performance. Plan for any temporary storage of moorings prior to deployment. Consider removal/decommissioning implications during the design and installation phases.

Pre WES	**WES Stage 1**	**WES Stage 2**	**WES Stage 3**
☐ Create high-level overview of cabling (including any intermediate hubs) and mooring configurations anticipated for the device.	☐ Establish initial understanding of loadings for foundation and mooring design.	☐ Update mooring and foundation design from Stage 2 to Stage 3 testing to include; ○ Extra masses involved; ○ Wave and tidal conditions for modelling of loads and estimation of ease of maintenance; ○ Any new and novel components or approaches, and how these have been de-risked through component testing. ☐ Review with marine contractor the mooring design, with particular focus on installation and maintenance of moorings.	☐ If any of the design inputs for the mooring/foundation change, then revisit the design to ensure the TPV is still valid. ☐ Ensure commissioning and installation of mooring design is followed to specification.

Relevant Industry Standards, Guidelines

Equimar D7.3.2 Consideration of the cost implications for mooring MEC devices http://tethys.pnnl.gov/sites/default/files/publications/EquiMar_D7.3.2.pdf
DNV-OS-E301 Position Mooring https://rules.dnvgl.com/docs/pdf/dnvgl/OS/2015-07/DNVGL-OS-E301.pdf
DNV Guidelines on Design and Operation of Wave Energy Converters http://www.gl-group.com/pdf/WECguideline_tcm4-270406.pdf
EMEC Guidelines for reliability, maintainability and survivability of marine energy conversion systems, 2009 http://www.emec.org.uk/guidelines-for-reliability-maintainability-and-survivability-of-marine-energy-conversion-systems/

Inspection and monitoring	Aim: Ensuring that suitable means for inspection and monitoring have been considered and put in place covering integrity, performance, environmental interactions, safety etc.

Structural, electrical (ship to shore) and environmental (site) inspection and monitoring plans are suggested and in some places required. It is suggested that there be an initial vetting of contractors, and some degree of ongoing oversight to ensure standards are maintained. Upon device delivery from non-local locations, consider inspecting and containing non-native species within and upon the device. Undertake a pre-operations survey of deployed equipment such as moorings before mobilisation if there is any risk of displacement or damage that could significantly affect operations. Inspection of seabed prior to deployment, and verification of seabed conditions after deployment are required by regulators.

Pre WES	WES Stage 1	WES Stage 2	WES Stage 3
☐ Be aware of the benefit and statutory requirements for inspection and monitoring of internal components, the whole system, the resources and environmental impacts to reduce failure and downtime of the device.	☐ Identify and plan for inspection and monitoring requirements.	☐ Develop a FAT for the commissioning of the Stage 3 device.	☐ Carry out required environmental monitoring plan to satisfy regulator. Ensure the tools and procedures are in place to satisfy the compliance plan. ☐ Apply a rigorous approach of photographing the complete installation activities to capture placement of all components, ties etc. Photograph everything coming out to capture wear patterns, corrosion, fouling etc. ☐ Maintain and monitor a detailed site plan identifying all subsea assets, including those buried. ☐ Conduct a post decommissioning survey immediately after all removal works have been completed.

Relevant Industry Standards, Guidelines
EMEC Guidelines for manufacturing, assembly, and testing of marine energy conversion systems, 2009. http://www.emec.org.uk/guidelines-for-manufacturing-assembly-and-testing-of-marine-energy-conversion-systems/