WES Development Guidance – Lessons Learnt from Real Sea Deployments

Guidance on Handling

WES_KH03_ER_03

Revision	Date	Purpose of issue
1.0	22/03/2017	WES External Issue

Project Participants

Contents

1 Introduction 1
2 Onshore Handling 3
2.1 Lifting and Handling Plan 3
2.1.1 Device Configuration 3
2.1.2 Lifting 4
2.2 Road Transport/Route Planning 5
2.3 Risk Management 6
2.4 Environmental and Site Consideration 6
3 Offshore Handling 7
3.1 Lifting and Handling Plan 7
3.2 Risk Management 8
3.3 Environmental and Site Considerations 8
4 Conclusion 9
4.1 Checklist Definitions 9
Appendix A: WES Development Pathway and Checklist Proformas 11

List of Figures

Figure 1 – Lift activities workflow 5

List of Tables

Table 1 – Checklist definitions 10

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
CoB	Centre of Buoyancy. The central point of buoyancy.
CoG	Centre of Gravity. The centre of mass in air, with no buoyancy considerations.
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. The government regulatory body that issues marine licences and Section 36 consents.
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.
PIC	Person in charge
PPE	Personal Protective Equipment
PR	Public Relations
Proforma	Pre-prepared form for the capturing and presentation of specific data.
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 Stage	A series of defined steps along a technology's TRL progression.

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 handling and most specifically onshore and offshore lifting and handling aspects. The sections are not exhaustive; however these were discussed as important topics during the OSC workshops.

The main Sections covered under Handling are:

- Onshore and Offshore Handling and Lifting plan
- Risk management
- Onshore and Offshore handling and lifting activities

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

The blue highlighted boxes 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 guidance document are checklist proformas relevant under handling. Only handling specific topics have been covered within these checklists. Throughout the checklists, it is clear that the OSC advises developers to prepare well in advance, ensuring sufficient plans are in place to facilitate efficient, and safe handling operations.

[1]Lifting Operations and Lifting Equipment Regulations (LOLER) 1998. ACoP and guidance. http://www.hse.gov.uk/pubns/priced/l113.pdf

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) 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 2015, 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.

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 of handling. A description is provided separately[2] 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.

Handling generally means any physical interaction; such as lifting, transporting or working on or around a marine energy device/subsystem or component, and can be defined in terms of mobilisation, demobilisation, onshore delivery and offshore delivery activities. The OSC identified aspects of handling that link into compliance (licensing and risk management), installation, recovery, operations, and maintenance of a marine energy converter and subsystems, and these are discussed below. Procedures are not discussed in terms of 'how to', but more importantly an overview of requirements involved in the safe handling of a device and the associated recommended work practices.

It is also recognised that onshore, quay to sea and offshore handling involves a range of operators including vessel owners, logistical experts, marine contractors, haulage companies and crane operators. As mentioned in the compliance guidance document, the Construction Design and Management regulations (CDM) require the device designer to adopt early consideration of handling activities to ensure the safe planning, management, risk identification and execution of these activities.

[2] WES_KH03_ER_01 – Approach and Supply Chain

The key issues highlighted during the OSC workshops were those involving the device configuration, device loads, centre of gravity (CoG) and lack of appropriate lifting points on the device. It is important that the needs for all lifting and winching equipment have been identified, including contingency lifts (unscheduled maintenance lifts for example), and that all suitable and available lifting equipment has been identified and utilised.

The recommendation is at WES Stage 1 the designer can describe how the device will be handled including both the onshore and offshore movement of the device. By WES Stage 2, engagement with a competent onshore/offshore marine contractor to support development of lifting plans, especially for complex lifts takes place. At WES Stage 3, lift tests should be implemented for bespoke and large equipment prior to deployment.

This document only includes issues related to handling 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 they fully adhere to safe handling activities.

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 Onshore Handling

2.1 Lifting and Handling Plan

Development of a lifting and handling plan will ensure that the required onshore support facilities and resources can be provided to their best effect to meet the programme objective of getting the device deployed safely and cost effectively. It is recommended at Stage 3 that a developer should demonstrate that a suitable overall onshore and offshore operations plan is in place. The supply, manoeuvring, working areas and storage of devices and ancillary enabling equipment are key requirements to include within the plan. It is advisable where "equipment parking" areas are needed, to be arranged and paid for and have potential access and availability issues covered. For example, in areas with other marine activities (renewables, fishery, or ship building) these activities can limit how you move, work on and store your device and equipment. Device design must consider handling procedures and not just when a device is deployed. Delivery and handling therefore need to be strategically planned from the outset.

There have been examples where this aspect has been neglected, with some equipment mobilised to Orkney with no provision made for where it would be stored or how it would be handled. Furthermore, the need to redesign poorly planned lifting methods has previously led to expensive lifting equipment being mobilised for months without being used.

It is recommended that a site visit occurs early in Stage 2, taking into consideration the infrastructure and equipment necessary.

2.1.1 Device Configuration

Equally important is an understanding of all dynamic loadings including sudden loadings during transfer/recovery of device and equipment between onshore and offshore lifting activities. This includes the test tank facility lifting equipment capabilities for the small scale prototype device. Working with the same crane operator or logistics expert to both plan and execute the critical lifting activities will improve time and cost to installation. It is also important to include a dismantling plan that takes into account potential changes in weight or failure of a component or subsystem interface.

At the Pre-WES Stage an awareness of the structural integrity of the wave energy converter, its subsystems and components, and the mechanics of failure should be understood. At WES Stage 3 and beyond, any structural changes, such as adding components or redesigning ancillary assemblies, should not compromise the structure or loading design. It is important to deliver a fully representative 'As Built' report to inform the contractors who will be considering/completing the handling, installation, recovery and decommissioning activities.

Have you fully considered the integrity and stability of the device / subsystem / components and the conditions which they will be under during lifting? (Stage 2)

Have you identified where the appropriate lifting points will be on the device? Have you taken into consideration the tank testing facility lifting capabilities? (Stage 2)

2.1.2 Lifting

The key principles[3] to safe lifting activities and what they include;

- Planning – the lift plan, HIRA and assessment of lift method, equipment and people
- Control – Person in charge of lift (PIC); PIC and lift team clearly understand the plan, method to control lift and individual responsibilities during the lift.
- Competence – PIC and lift team trained and competent for their role.
- Equipment – fit for purpose, designed to recognised standard, safety devices installed.
- Inspection, Maintenance and Certification – maintained equipment integrity, 12 months inspections of equipment, all lifting equipment will be visually examined before use.
- Load Integrity and Stability – load shall not exceed dynamic and / or static capacities of the lifting equipment. Integrity and stability of loads will be verified before lifting
- Lifting of Personnel – shall be avoided, unless risk is ALARP.
- Management Systems – lifting operations shall be in accordance with company management system (IMS).

Prior to the device and supporting/enabling equipment arriving on site, it is strongly recommended to follow the guidelines of LOLER. Understand the lifting requirements and then work with an experienced lift operator to review and approve the lift plan. The following are the critical requirements for lifting a device;

- Lifting/winching/tag line points on the device are sized appropriately, certified and located optimally in an accessible position on the device/structure.
- Understanding of which areas on a device are sensitive to loading, with “no lift” or “no standing” clearly labelled.
- Peer reviewed and approved lifting and winching plan is in place.
- Available lifting and haulage capacity of local vessels is fully understood under static and dynamic conditions.
- Lifting transitions are considered (for example, from trailer to pier, from pier to water, from vessel to water).
- Device mass, centre of gravity and centre of buoyancy are fully understood and mitigated to avoid any interventions that would alter these parameters are identified.
- Control of device and personnel is maintained during lifting/winching operations.
- Ensure regulations and standards are followed e.g. LOLER[4]

Below is a sample workflow that can be followed for organising and planning lifting activities.

[3] International Association of O&G producers Lifting and hoisting key principles http://www.iogp.org/Lifting-hoisting-safety#4504393-key-principles

[4] Lifting Operations and Lifting Equipment Regulations 1998 (LOLER): http://www.hse.gov.uk/work-equipment-machinery/loler.htm

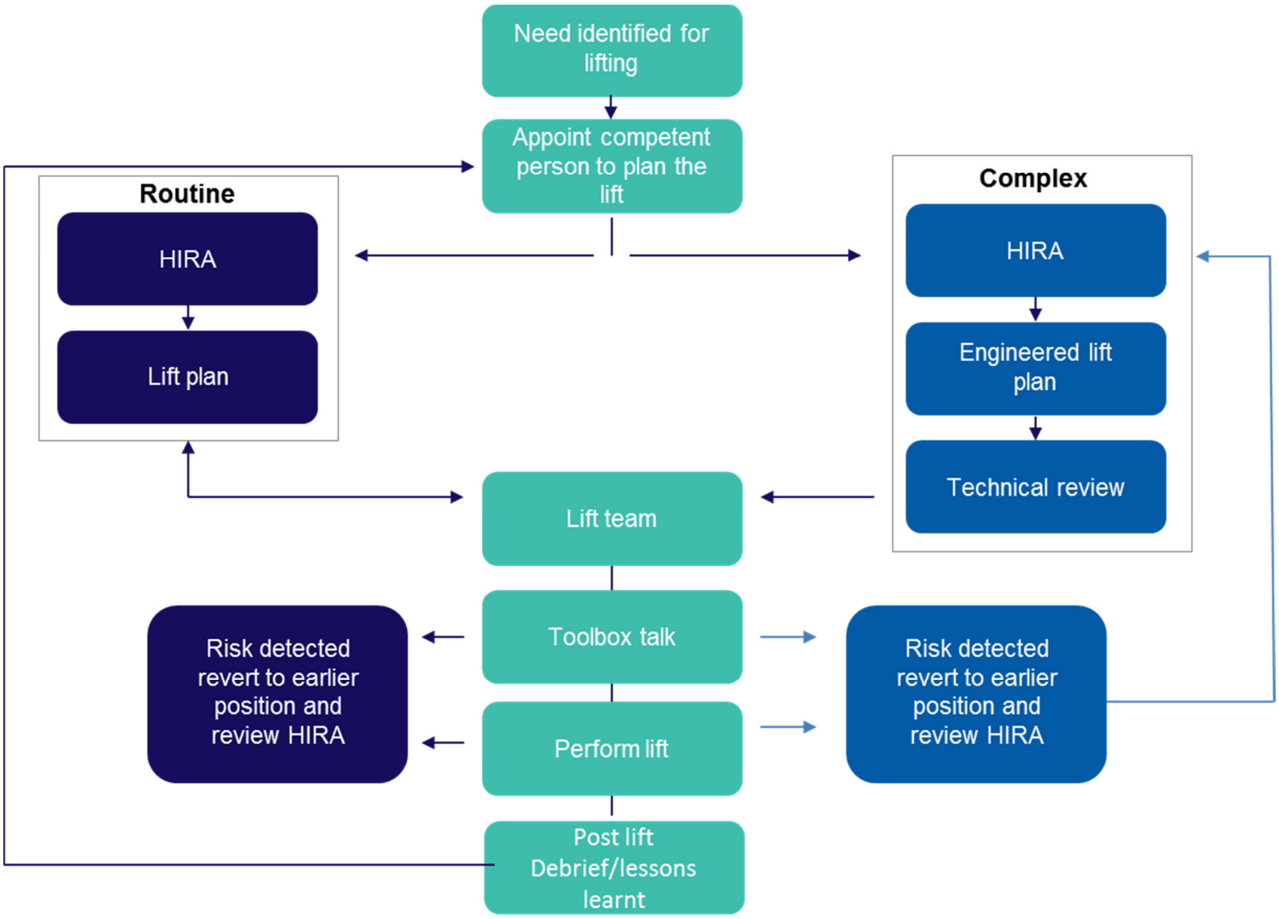

Figure 1 – Lift activities workflow

Have you engaged with a logistical (local) expert in development of your device handling plan? (Stage 2)

Have you considered inspections before and after delivery of device to the site prior to lifting? (Pre WES)

Has lift equipment been certified? (Stage 3)

2.2 Road Transport/Route Planning

Road transport has been an issue with local councils when not addressed in good time with appropriate consultation. The size and weight of the load, in conjunction with the transport vehicle and trailer gross tonnages, should be understood and any required permits applied for. Roads at remote sites may also be limited in width and tight bends may cause issues. Therefore, doing an initial site review to plan the route is highly recommended.

It is essential to include a transport management plan to capture the limitations and requirements of the local road conditions and capacities. All the above plans should be incorporated into sections in an overall operations plan. Diagrams and drawings are excellent tools to visually describe the transport routes.

The approach to land transport and routing could be influenced by the local authority's (or national bodies, if using trunk roads) road restrictions or permits that are necessary to move heavy or unusual loads. It is necessary to also consider the UK and international custom controls if importing/exporting the device.

Where devices, components or subsystems are transported by sea from other areas, care should be taken to ensure environmental protocols are in place. The issue is the accidental movement or introduction of non-native species. The EMP and the requirements noted in site permitting documents rarely include references to this aspect on environmental protection, so care must be considered during planning.

Have you visited the site and understood the route the device will take from land to sea? (Stage 2)

Have you consulted with the local road authority? (Stage 2)

2.3 Risk Management

H&S is discussed in detail in the guidance on compliance, and O&M. It is recommended when evaluating your handling plans for completeness you incorporate the topics from the O&M guidance, such as work in confined spaces, electrical operations, and the CDM approach when defining the handling activities. Statistics from the Health & Safety Executive UK on injury, health and incident in 2012/2013 demonstrate the seriousness of appropriate handling plans that are fully de-risked. The report states, 'injuries from handling, lifting or carrying' produced the most injuries in a single category followed by 'struck by moving objects',' slips',' trips', 'falls' and 'falls from height'. These four categories account for 90% of all injuries reported.[5]

As in all the other marine activities discussed within the suite of guidance's, a Hazard Identification and Risk Assessment (HIRA) should be carried out by the end of WES Stage 2 to identify the key risks involved in handling the device/subsystem or component onshore, from manufacturing site, to quayside. The HIRA should include critical component risks (i.e. what is most likely to fail during handling/lifting of a device). For example, trailing cables are at high risk of damage during lifting operations.

As the project moves from Stage 2 into Stage 3, updating, reviewing and communicating the risks with all involved in the movement of the device will ensure contingencies and efficiencies are in place for safe and cost effective transportation and delivery of the device to onshore site.

Have all risks been identified, registered and mitigated for? (Stages 2 and 3)

Have risks to those involved in movement of the device from manufacturing site to the test site been identified? (Stages 2 and 3)

2.4 Environmental and Site Consideration

The primary environmental consideration is weather. Planning lifting activities during high winds increases risk of uncontrollable movement of the device. Additional points to consider are the protection of components and subsystems prior to full assembly, as these may be

[5] HSE UK Offshore injury, ill health and incident statistics. http://www.hse.gov.uk/offshore/statistics/hsr1213.pdf

vulnerable to wind and rain. Weather patterns change in different seasons, making summer the preferred time to plan handling activities where there is a choice.

At the EMEC site, located off the north coast of Scotland, metocean conditions go from extreme sea states in the winter months to lowered sea states in the summer months. The average yearly winds velocity is 6 m/s. With conditions deteriorating usually in autumn through winter and spring, gale force winds are more frequent and wind gusts up to 60-70 mph is frequent. Because of its northern location, daylight availability for operations in the summer can be up to 12 hours, with calm conditions for installations.

As mentioned in planning it is critical to visit the site to understand the environmental and site conditions. Determining the route from arrival point to onshore site to quay side will bring an appreciation of conditions unique to the site. The infrastructure needs may not be available in reality. By including a review of the space requirements where the device will be stored during onshore maintenance, including the proximity of where power/grid connection and other support equipment would be placed is critical. Experience has shown the awkward shape of some devices do not allow for entry into a typical 2.5 m storage unit on Orkney.

Have you planned and prepared for a site visit? (Stage 1 and 2)

3 Offshore Handling

3.1 Lifting and Handling Plan

As for shore based handling, a well-developed and third party peer reviewed lifting and handling plan can help keep the OPEX budget in check.

The costs associated with heavy (over 25 tonnes) lifting at sea are considerable and should be avoided wherever possible. A towing methodology can be effective in limiting lifting activities between quayside and sea. If the device is designed to roll on, roll off from a slipway to the sea easy connection/disconnection for towing to site is a cost effective method.

Another aspect of handling most developers are unaware of are the remote conditions at the site including where the grid substation is located. Most sites are only accessible via a vessel, for towing or transporting a device and/or personnel. The route back to the maintenance harbours can take up to an hour. Thus for efficient maintenance activities if available on site it is important to locate and have on standby the equipment needed for remote site maintenance.

As discussed above in onshore handling and lifting, planning full HSE requirements and industry best practice (LOLER) should be followed at all times for lifting operations. Again following the above lifting workflow and the principles behind lifting will de-risk lifting operations at sea. (See Figure 1)

Installation and ongoing maintenance of moorings, foundations or anchors will require deployment and recovery plans. These plans will involve towing, lifting and handling activities. Depending on how bespoke the moorings are, these may sit within standard offshore operations for the marine contractor, or require a detailed lift plan, with diagrams and HIRA to cover potential new risks. Again it is emphasised lifting plans should be designed with appreciation of the dynamic loads under which the device will be exposed to.

As with the lifting and handling of the device onshore, electrical cables and umbilical lifts at sea are also a challenge, especially in near shore areas with wave action. The cables can undergo dynamic motions (e.g. twisting which result in kinks), which limits vessel movement during operations. It is advised to plan early reviews with contractors experienced in cost efficient cable laying and recovery activities.

Are you aware of the proposed remote site conditions, potential lack of equipment, and the impact to lifting activities? (Pre WES)

3.2 Risk Management

Handling of wave energy converters, their subsystems and components is influenced by external change. The marine space is shared by other vessels and the transit and loading and offloading activities of other vessels potentially have an impact on the WEC deployment activities. Handling can be particularly vulnerable to schedule changes when crane availability is limited and/or weather conditions deteriorate. It often requires adjustments to the operational activities, sometimes affecting the ability to complete the operation during the target weather window. These aspects should be built into the risk register and contingency plans.

A risk to the handling plan is the immediate availability/cost of vessels, especially those that offer services to the wider offshore market. The vessel capacity market can change dramatically based on season and external demand. This issue can be compensated for by either budgeting the upper levels of cost for immediate availability, building flexibility into planning so that a developer can wait until the costs are within budget, or finally by booking well in advance which can lock in vessel availability at a known cost.

All the aspects discussed here should be built into the technology risk register and contingency plans.

3.3 Environmental and Site Considerations

The key environmental issue affecting handling offshore is weather and most specifically wind, wave current and tidal conditions. Other conditions such as air and sea temperature, visibility and ice conditions are also important. With rapidly deteriorating conditions in the sea state, the increase in environmental loading will negatively impact the stability of the device, exponentially increasing the operational and personnel risks. There will be a need to postpone or call off any device installation activities. Using an O&M tool to help in planning deployments is strongly recommended with expected improvement in efficient and cost effective operations, while working within the appropriate seasonal weather windows. In addition, the local vessel operators who have an awareness of the site conditions and forecasts, will inform decisions at key ‘break points’ in the operations as to whether the best course of action is to continue, or move towards a “safe state” abandonment.

Communications is discussed in detail in the O&M guidance however, during offshore handling activities the field of communication becomes very tight. In other words the activity at the site must be relayed from the deck of the vessel to the captain who is holding the vessel in position while keeping aware of communications coming from other vessels in the vicinity. The backup communications systems (VHF radio), and GPS positioning/ marine radar between vessels and from vessels to shore will help de-risk any issues with communications in deteriorating weather conditions.

Are you aware how the full system stability would respond during deteriorating conditions while alongside operational vessels. (Pre WES and Stage 2)

4 Conclusion

In summary, successful and safe handling activities are achieved by creating and maintaining a strong H&S culture, beginning with a handling and lifting plan which should be put in place at the earliest possible instance. Risk assessment is a key activity in management of safe handling operations with a sound understanding of the environmental and site conditions the handling activities will be carried out in. Ensuring the handling and lifting plans are part of the overall operations planning stage, along with third party peer review of the mobilisation and demobilisation of the WEC, will meet the required CDM regulations covering lifting and handling.

There are a number of industry guidance's referred to above and it is important to keep up to date with the following organisations as they update handling and lifting best practices. They are:

- The Health & Safety Executive www.hse.gov.uk/index.htm
- International Association of O&G producers www.iogp.org
- International Marine Contractors Association www.imca-int.com

Following are the handling 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.

4.1 Checklist Definitions

The Checklist threads below in Table 1 are the priority checklist items covered in detail with the Orkney Supply Chain (OSC) and prioritised under the handling 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.

Thread	Definition
Operations planning	Ensuring that each operational stage, whether in a laboratory, factory, on land or at sea, is effectively planned and executed.
Site conditions	Ensuring that the specific influences of environmental, social and industrial site conditions on design and operations are understood. This includes taking into account both the laboratory and factory conditions and onsite reality of onshore and at sea conditions.
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.

Thread	Definition
Connections and Moorings	Enabling technologies are certified fit for purpose, use proven solutions where possible and build upon local site experience and capacity.
Lifting and Winching	Ensuring that the needs of all lifting and winching operations have been identified, including contingency lifts, and that suitable/available lifting mechanisms are in place and that each lift is planned appropriately.

Table 1 – Checklist definitions

Appendix A: WES Development Pathway and Checklist Proformas

Throughout the development workshops the documentation of supply chain issues and recommendations took the form of proformas. The workshops were designed to build the proformas and indicate which specific topic and associated issue were important to address at which WES 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 proformas for each of the prioritised OSC threads 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 local supply chain will bring intangible benefits to the design process, particularly from experience of the site conditions and understanding 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, 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, utilise local 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 future 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 incorporate 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 requirement 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 with the general public. ☐ 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. ☐ Plan for transit to offshore site.

			☐ 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

Site conditions	Aim: Ensuring that the specific influences of environmental, social and industrial site conditions on design and operations are understood.

This includes taking into account both laboratory and factory conditions and onsite reality of onshore and at sea conditions. In early stages of concept design consideration of separate component tests in offshore site conditions is less expensive than building a full scale system for survivability, reliability and performance testing. The feedback and knowledge gained can inform an integrated system and subsystem concept refinement and optimisation. The physical oceanographic and hydrodynamics of the site describe the range of conditions that may be experienced over time and space, this is vital for modelling overall performance. Onshore site conditions are critical to understand, for example seasonal weather which impacts device handling. Early engagement with local marine contractors who have knowledge of the environmental and practical site conditions can improve device design and deployment planning.

Pre WES	WES Stage 1	WES Stage 2	WES Stage 3
☐ Describe in concept feasibility what types of site conditions your device is targeted at and may be sensitive to.	☐ Show through preliminary analysis how structural integrity is achieved and maintained. ☐ Materials considered should demonstrate evaluation against corrosion or other mechanical/ structural failure of device	☐ Select Stage 3 test site(s) and schedule site assessment visits. ☐ Collate and manage environmental site data, identifying gaps against the design parameters, evaluate the use of modelling tools incorporating environmental data and hydrodynamics to describe range of conditions that may be experienced on site over time and space. ☐ Prepare weather window scenarios incorporating wave/tidal hind cast data. ☐ Establish site data requirements for any onshore sites. ☐ Develop plans for welfare needs and human logistics as part of onshore planning. ☐ Plan for remote site maintenance facilities with spares and toolkits.	☐ Verify that site conditions have remained consistent since the surveys undertaken by taking into consideration any additional data for the site that has become available.

Relevant Industry Standards, Guidelines

EMEC Guidance on Assessment of Wave Energy Resource http://www.emec.org.uk/assessment-of-wave-energy-resource/

IHO (International Hydrographic Organisation), 2008 Standards for Hydrographic Surveys

IEC TS 62600-101:2015 Marine Energy, Wave, tidal and other water current converters – Part 101: Wave energy resource assessment and characterisation.

Device structure	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.

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.

Pre WES	**WES Stage 1**	**WES Stage 2**	**WES Stage 3**
☐ Awareness of the importance of appropriate structural integrity within the concept feasibility work.	☐ 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.	☐ 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.	☐ 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.

Relevant Industry Standards, Guidelines

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.

<table>
<tr><td>Connections, moorings and foundations</td><td colspan="3">Aim: Enabling technologies are certified fit for purpose, use proven solutions where possible and build upon local site experience and capacity</td></tr>
<tr><td colspan="4">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.</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>☐ Create high-level overview of cabling (including any intermediate hubs) and mooring configurations anticipated for the device.</td><td>☐ Establish initial understanding of loadings for foundation and mooring design.</td><td>☐ 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.</td><td>☐ 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.</td></tr>
<tr><td colspan="4">Relevant Industry Standards, Guidelines</td></tr>
<tr><td colspan="4">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/</td></tr>
</table>

Lifting and winching	Aim: Ensuring that the needs of all lifting and winching operations have been identified, including contingency lifts, that suitable/available lifting mechanisms are in place and that each lift is planned appropriately

Lifting and Winching activities require understanding of respective standards. LOLER and PUWER are related standards to embed within lift plans. Further guidelines are available from different industries and worldwide. A good example of this is the documentation available from the IMCA (International Marine Contractors Association). Ensure lifting and winching points are optimised in design (scale/location). Demonstrate that lifting and winching operations on or involving water have increased safety margins to account for dynamic loads. Remember to check all lifts from the fabricators yard, to road transport, sea transport, quayside, and open water, ensuring there is lifting capacity sufficient at each step taken. Importing lifting capacity to remote locations is possible but very expensive, so if total mass can be controlled through restrained design, or modularity then there may be significant cost savings. Account for added mass and possible failure of certified lift points during decommissioning phase planning, as devices may experience flooding, marine growth or corrosion.

Pre WES	**WES Stage 1**	**WES Stage 2**	**WES Stage 3**
☐ Describe conceptually how the device will be handled, including both onshore and offshore aspects.	☐ Awareness of approximate weights and weight distribution of test device. ☐ Check with test tank what assets are available for lifting and winching in preparation for tank testing. ☐ Ensure feasibility of Stage 3 full scale lifts.	☐ Plan lifts for each stage of the device handling process. ☐ Start planning of Stage 3 lifts including expert advice to capture dynamic loadings and transfer between on and offshore lifting. ☐ Engage with companies with regards to lifting gear availability for Stage 3.	☐ Identify need for test lifts of bespoke equipment, and implement as required to de-risk operations ☐ Follow lift plans during all lifting activity. Note deviations from the plan to refine future operations ☐ Include short and long term storage and laydown areas required for both operational plans and associated contingencies ☐ Consider if lift points will still be within certification on the dates needed bearing in mind proof loading may not be possible underwater.

Relevant Industry Standards, Guidelines

Lifting Operations and Lifting Equipment Regulations 1998 (LOLER), Provision and Use of Work Equipment Regulations (PUWER) http://www.hse.gov.uk/work-equipment-machinery/loler.htm and http://www.hse.gov.uk/work-equipment-machinery/puwer.htm

IMCA http://www.imca-int.com/safety-environment-and-legislation/safety-flashes/2016.aspx