Open Sea Operating Experience to Reduce Wave Energy Costs

Deliverable D6.3

Recommendations and guidelines for offshore operations for wave energy converters

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EXECUTIVE SUMMARY

WP6 of the OPERA project focuses on lifetime offshore logistics of a floating OWC (MARMOK-A5) with a goal to reducing the uncertainty on, and optimising, the risk and cost of offshore operations. The aim of this deliverable is to report lessons learnt, recommendations and strategies for cost reduction of offshore operations developed during the OPERA project.

After an initial description of the test sites and MARMOK-A5 device, this deliverable presents an analysis of the offshore operations logged in the project. During OPERA, more than 90 offshore operations have been performed in three years. Then the application of Health and Safety regulations is discussed. The exchange of practical experiences among offshore participants and consortium partners has been recorded with a view of identifying best practices and lessons learnt.

Offshore logistics and procedures documented in the previous WP tasks have been synthesized as actionable recommendations, focusing on decision-support and uncertainty reduction for issues facing wave energy project developers at various levels. Specific issues include de-risking operations, evaluation of site accessibility, refining assessment of access limits, optimising maintenance schedule, grouping operations and other cost reduction strategies.

Practical lessons have been included such as recording of maritime operations and design requirements to facilitate maintenance operations such as easier connection/disconnection, safer design access and necessary room for maintenance operations inside the hull. These newly de-risked specifications for wave energy shall be compared to relevant offshore oil & gas requirements, which still guide maritime operations in ocean energy despite presenting fundamentally different risks to human life and the environment.

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ABBREVIATIONS AND ACRONYMS

AHT	Anchor Handling Tug
ALARP	As Low As Reasonably Practicable
BiMEP	Biscay Marine Energy Platform
BWEA	British Wind Energy Association
BV	Bureau Veritas
CLV	Cable-Laying Vessels
DP	Dynamic Positioning
DPO	Dynamic Positioning Operator
FMEA	Failure Mode, Effect Analysis
GT	Gross Tonnage
HAZIP	Hazard Identification
HAZOP	Hazard and operability
H&S	Health and Safety
H_S	Significant wave height
HSE	Health, Safety and the Environment
IMO	International Maritime Organization
LSCS	Load Shackle Cable System
MRE	Marine Renewable Energy
O&M	Operation and Maintenance
OPEX	Operational expenditures
OWC	Oscillating Water Column
PPE	Personal Protective Equipment
PTO	Power Take Off
RA	Risk Assessment
RCO	Risk Control Options
ROV	Remote Operated Vehicle
T_P	Peak wave period
TRL	Technology Readiness Level
WEC	Wave Energy Converter
WP	Work Package

1. INTRODUCTION

The offshore logistics and procedures documented in the previous tasks (T6.1 and T6.2) have been synthesized as actionable recommendations, focusing on decision-support and uncertainty reduction for issues facing wave energy project developers at various levels. Specific issues include de-risking operations, evaluation of site accessibility, refining assessment of access limits, optimising maintenance schedule and grouping operations.

Practical lessons have been included such as recording of maritime operations and design requirements to facilitate maintenance operations such as easier connection/disconnection, safer design access and necessary room for maintenance operations inside the hull. These newly de-risked specifications for wave energy shall be compared to relevant offshore oil & gas requirements, which still guide maritime operations in ocean energy despite presenting fundamentally different risks to human life and the environment.

1.1 SCOPE OF THE REPORT

The objective of WP6 is to reduce uncertainty on and optimise risk and cost of offshore operations.

In offshore renewable OPEX is roughly a third of cost of energy, of which offshore operations typically is the major contributor. Offshore operations also have a major impact on Life Cycle CO_2 emissions. Although similar importance is expected in wave energy farms, the lack open-sea experience shared across the sector introduces major uncertainty on expectable OPEX in wave farms, which introduces a costly business risk in wave energy projects. Documenting and sharing information on offshore operations in OPERA is a major opportunity to achieve decisive progress on this front.

WP6 focuses on lifetime offshore logistics of a floating OWC with a goal to reducing the uncertainty on, and optimise, the risk and cost of offshore operations. Specific objectives:

- Improve operational models to more precisely reflect logistic requirements for floating OWC.
- Identify and optimise maintenance and operational procedures to lower life-cycle costs.
- Perform, improve and document required offshore operations during the open-sea testing period.
- Provide figures for OPEX calculation based on real open sea operations.
- Produce guidelines and recommendations that minimise risk and cost of offshore operations for wave energy.

To achieve these objectives, WP6 has been divided in four different tasks:

Task 6.1 Logistics needs characterisation

The characterisation of the **installation, operation, maintenance and decommissioning** of the device was based initially on the procedures carried out for its deployment and testing at real sea and adapted to specific OPERA requirements. This task has updated the initial planning of maritime operations developed by OCEANTEC prior prototype deployment.

Installation includes on-site port activities before the device is deployed at sea, device towing, heavy lifting or submerging, ballasting, securing to the seabed and connection to the grid. Apart from the device itself, installation operations will also encompass wave resource instruments, mooring, and turbine, generator and power electronics.

The **inspection**, **repair** and **maintenance** levels/frequency were adjusted to the reliability considerations of the prototype (OCEANTEC) and the limitations on weather windows accessibility to the site (BIMEP, UCC), including provisions for emergency situations. BiMEP provided real-time remote supervision and offshore surveillance services. Unscheduled maintenance actions were simulated in order to reduce risks and estimate realistic operating costs. In-service inspections and small repair were performed onsite, whereas large maintenance actions were done at Bilbao port. UCC defined the O&M logging framework to be used in subsequent tasks. Decommissioning operations and costs were considered with attention to the expected duration of a commercial project and its consequences on the lifetime cycle.

Task 6.2 Improve offshore logistics and cost models

Existing operational models for the estimation of the OPEX have been studied with data collected under real operating conditions and operational model has been developed, focused on the cost of offshore operations, whereas the cost of components to be replaced and other running costs such as insurance has been integrated in the overall cost model in WP7.

The task also collected information from all the other WPs on the probability of failure and the need for replacement of the equipment on board. Results have been used to feed into operational models for the OPEX calculation and O&M scheduling and has been validated against the effective failures and replacements occurring on site.

Modelling site accessibility assessment with estimation of weather windows and validation against real sea operations is also necessary to realistically assess the waiting time and costs.

Maritime strategies have been analysed using models for the operational simulation of offshore renewable devices.

Task 6.3 Monitoring of safe offshore operations and logistics

The implementation of all phases of the offshore operations have been carefully monitored and documented to update and reduce the uncertainty on the initially identified risks and risk levels. The applicability of existing guidelines from offshore oil & gas has been reviewed also in consideration of the health and safety requirements for renewables.

Task 6.4 Recommendations and guidelines

At this task the offshore logistics and procedures documented in the previous tasks have been synthesized as actionable recommendations, focussing on decision-support and uncertainty reduction for issues facing wave energy project developers at various levels. Specific issues will include de-risking operations, evaluation of site accessibility, refining assessment of vessel access limits, optimising maintenance schedule and grouping operations, spare part storage, conditions-based monitoring and contingency plans.

Practical lessons have been included such as recording of maritime operations and design requirements to facilitate maintenance operations such as easier connection/disconnection, safer design access and necessary room for maintenance operations inside the hull.

1.2 OUTLINE OF THE REPORT

The aim of this deliverable is to report lessons learnt, recommendations and strategies for cost reduction of offshore operations developed in task T6.3 and T6.4.

The report has been divided in five different sections:

- **Section 2:** This section introduces the **test sites and MARMOK-A-5 device**.
- **Section 3:** The **inventory and analysis of the offshore operations** reviews the offshore operations logged during the OPERA project. Based on this information, the O&M model has been recalibrated and final results compared with initial estimations.
- **Section 4: Health & Safety regulations applied along the offshore operations in the OPERA Project** have been discussed. Current standards and regulations for the offshore industry regarding offshore installation and O&M operations have been analysed.
- **Section 5: Lessons learned from offshore participants** have been documented. They come from two workshops hosted during the project lifetime as well as from partners' exchange of practical experiences.
- **Section 6: Overall conclusions** have been summarised.

2. DESCRIPTION OF THE TEST SITES AND MARMOK-A5 DEVICE

This chapter introduces BiMEP and Mutriku test sites [1] and Oceantec-Idom's [2] ,[3] floating OWC MARMOK-A-5 wave energy converter.

2.1 TEST SITES DESCRIPTION

2.1.1 BIMEP TEST SITE

BiMEP is an infrastructure for testing prototypes of marine energy devices and auxiliary equipment on the open sea. It is located off the coast at Armintza with exceptional conditions for testing the effectiveness of new mechanisms and technologies for harnessing wind and wave energy.

The infrastructure is equipped with four 13.2 kV/5MW subsea cables fitted with optic fiber and ending in some dry mate subsea connectors. It also provides the possibility of feeding in low voltage power (690 V). BiMEP also has an onshore substation fitted with 25 MVA 13.2/132 kV transformers. The test site occupies a 5.2km^2 area restricted to the shipping with perimeter beacons, the depths at it range from 50 to 90 meters and the seabed is mostly sandy with rocky areas.

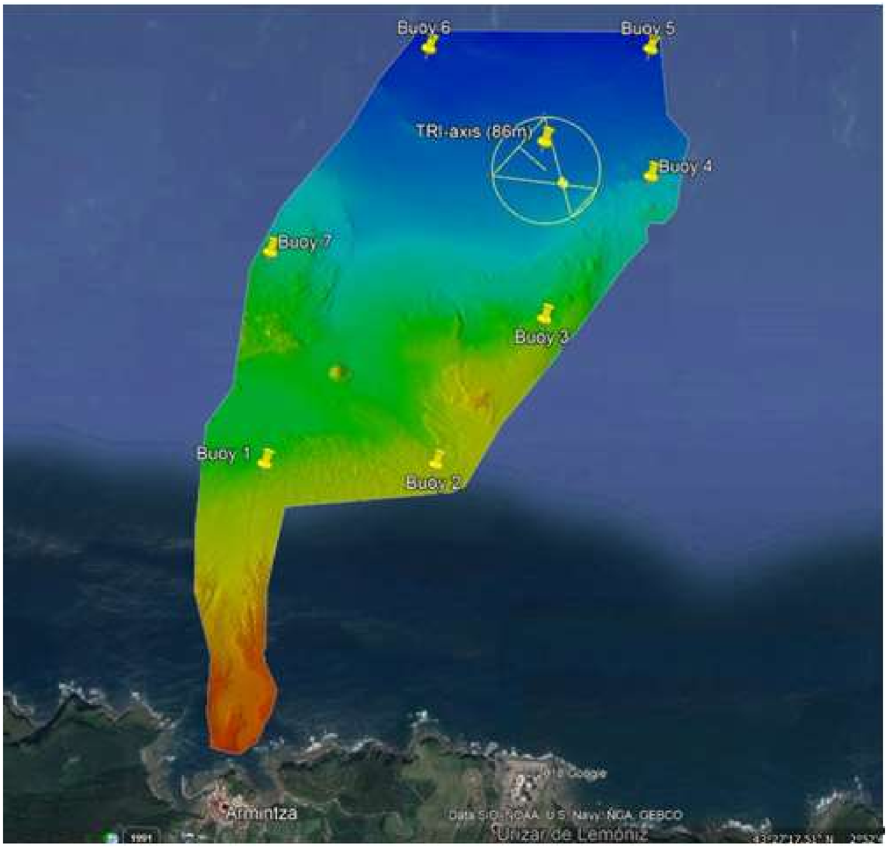


FIGURE 1 BIMEP TEST SITE BATHYMETRY, MARMOK-A-5 LOCATION

2.1.2 MUTRIKU TEST SITE

The wave energy plant at Mutriku is hosted inside the breakwater that protects its harbour, in the Bay of Biscay. The technology selected for the energy conversion is the oscillating water column (OWC) because of its simple and non-disruptive design (Figure 2).

FIGURE 2 MUTRIKU TEST SITE

The Mutriku test site is integrated into the wave energy plant at Mutriku with a total capacity of 296kW (16 chambers Figure 3) that was built into the breakwater at the harbour. It can host trials of new concepts of air turbine, control strategy and auxiliary equipment for OWC devices. Mutriku offers developers the possibility of testing, validating and demonstrating their designs, algorithms and equipment in real sea conditions but in controlled environment before jumping to the harsher offshore sites.

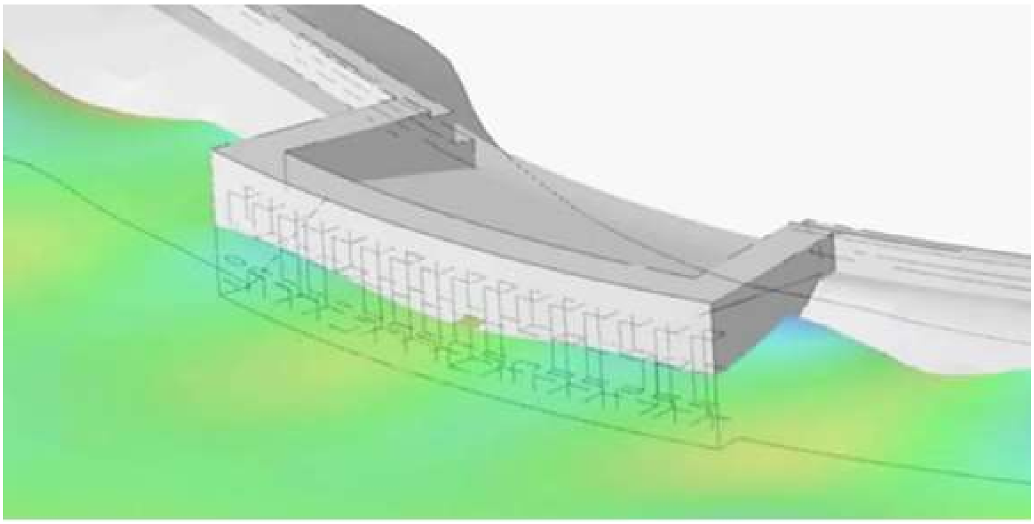
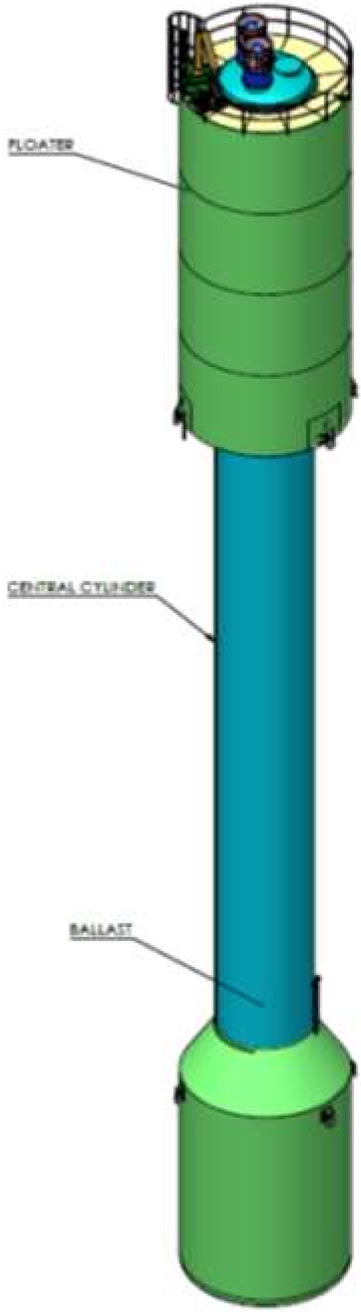


FIGURE 3 MUTRIKU TEST SITE 16 CHAMBERS

2.2 DESCRIPTION OF THE MARMOK-A-5 DEVICE

2.2.1 Baseline Configuration

MARMOK-A-5 device is a spar type OWC wave energy converter buoy. It is a 5m diameter and 42m long machine of 30kW rated power. Particularly, the power take-off system consists of a pair of Wells turbine of 15kW rated power each.



The buoy can be divided into three parts; the floater which adds floatability and holds all the electrical equipment and sensors including umbilical cable entry for grid connection, the central cylinder which holds the inner water column, and the water ballast tank which can be partially or fully emptied for buoys transportation and installation/decommissioning.

The mooring system consist of 4 catenary lines with drag anchors which are interconnected by a submerged rectangular cell made of steel wire ropes suspended from 4 pennant surface buoys. Those catenary lines are composed by chains and polyester ropes in their top end. MARMOK-A-5 is connected to the submerged cell by 4 polyester ropes.

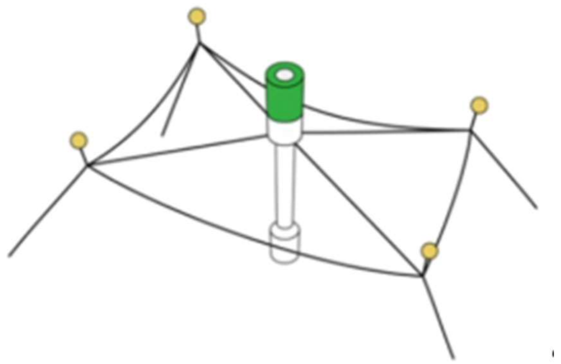


FIGURE 4 MARMOK-A-5 BASELINE CONFIGURATION

Figure 5 shows the MARMOK-A-5 installed at BiMEP. Yellow and purple lines represent the mooring steel wire and polyester ropes respectively.

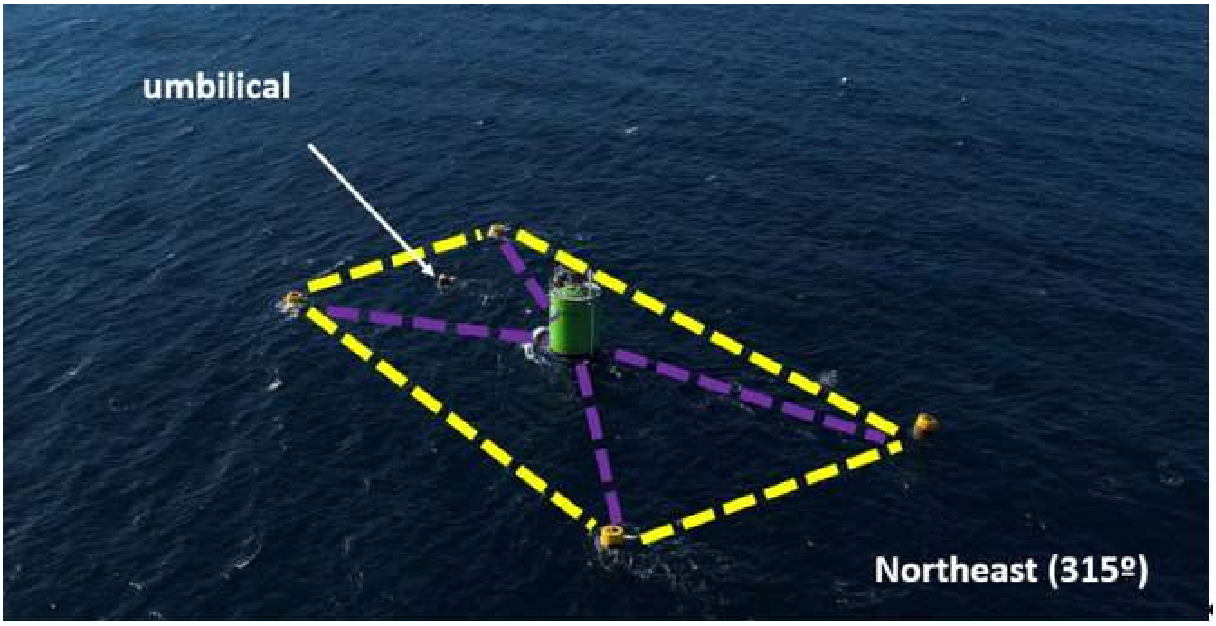


FIGURE 5 MARMOK-A-5 DEVICE

The motivation for using this design is to reduce the number of mooring and anchoring components, thereby reducing costs and increasing the reliability for arrays of MRE devices. More information available at public deliverables “Mooring Open-Sea Operating Data Analysis” [5] and Recommendations for WEC mooring guidelines and standard [6] .Figure 6 shows the mooring system lay-out front view.

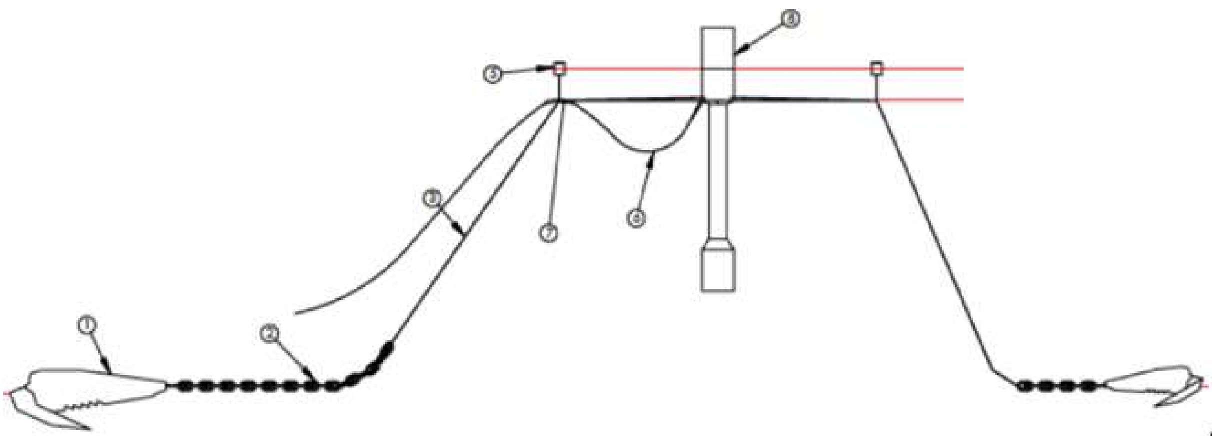


FIGURE 6 MOORING SYSTEM OVERVIEW FRONT VIEW

Figure 7 represent plant view of the mooring:

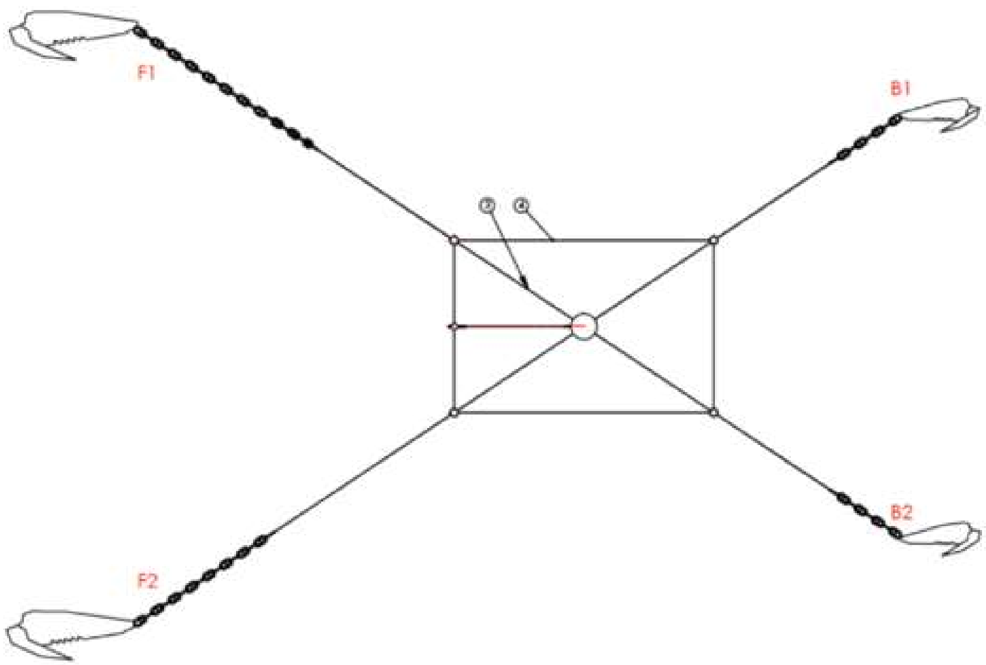


FIGURE 7 MOORING SYSTEM OVERVIEW, (TOP) FROMT VIEW, (BOTTOM) PLANT VIEW

Next table summarizes mooring details of each item of the mooring.

TABLE 1 DETAIL OF EACH ITEM OF THE MOORING SYSTEM

ITEM Nº	DESCRIPTION
1	ANCHOR
2	CHAIN
3	POLYESTER ROPE
4	STEEL WIRE CABLE
5	SURFACE BUOY
6	UMBILICAL CABLE
7	BEND RESTRICTOR
8	MARMOK-A-5

2.2.2 Final Configuration with Innovations

Following the baseline configuration deployment and testing, several innovations were included within the OPERA project. The two innovations with larger impact on the marine operations were the novel biradial turbine [8] , [9] and the elastomeric tethers [10] .

FIGURE 8 BIRADIAL TURBINE IN OPERATION AT BIMEP

Regarding the birradial turbine, following an extensive testing campaign in the Mutriku onshore wave power plant, it was installed on top of the MARMOK-A-5 buoy. Installation was performed on deck while buoy retrofitting. The top cover which held the two Wells turbines was substituted by the single biradial turbine. Figure 9 shows the biradial turbine on the top of the device.

FIGURE 9 BIRADIAL TURBINE AT MARMOK-A-5

Regarding the elastomeric tethers, following an extensive campaign of dry testing both at reduced and full scale in laboratory, a pair of ropes were installed through a dedicated marine operation substituting the conventional polyester ropes in the Northern lines (see previous section; mark 3 in F1 & F2 lines).

FIGURE 10 ELASTOMERIC TETHERS INSTALLATION MARINE OPERATION

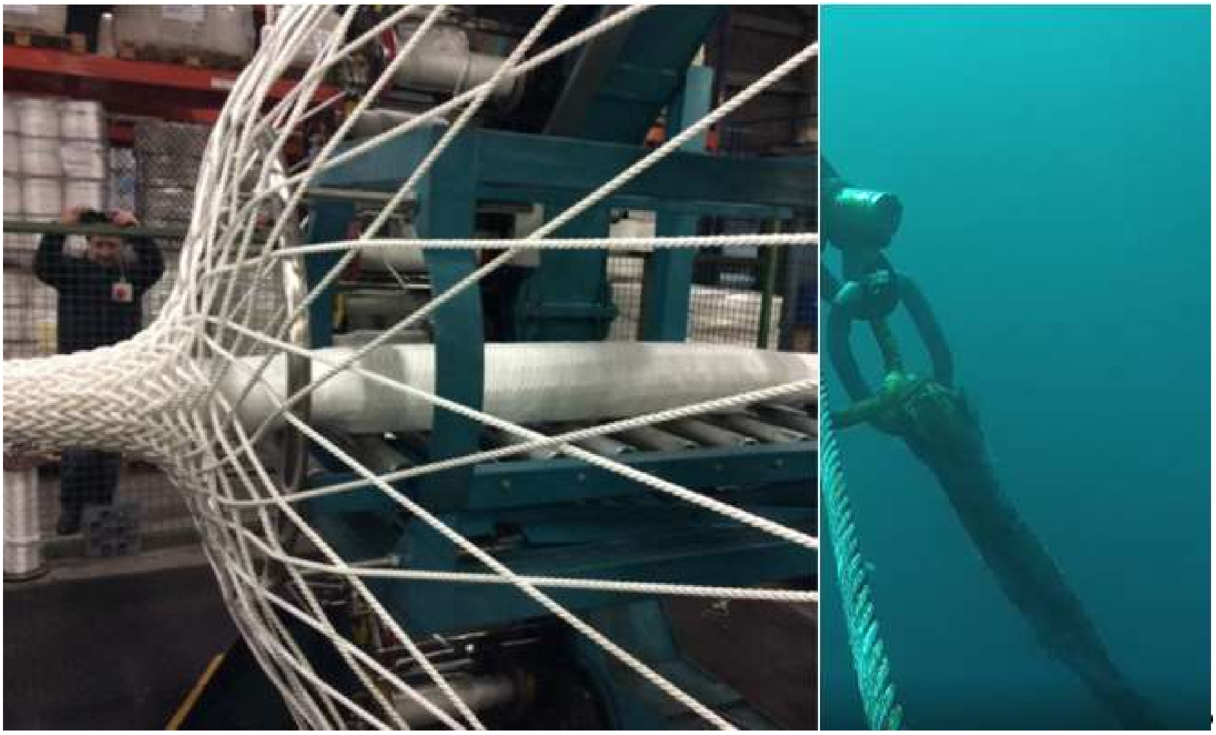


FIGURE 11 MANUFACTURING PROCESS AND UNDERWATER VIEW OF THE INSTALLED ELASTOMERIC TETHER

3. INVENTORY AND ANALYSIS OF THE OFFSHORE OPERATIONS PERFORMED IN OPERA

During the OPERA project, all offshore operations have been thoroughly documented, analysed and studied to improve next offshore operations. Whenever possible, different operations have been combined to reduce costs. The following sections summarises the different operations carried out and the result of tuning O&M model developed in task 6.3 based on the information collected.

3.1 OFFSHORE OPERATIONS PERFORMED IN OPERA

3.1.1 OVERALL SUMMARY

More than 90 offshore operations have been performed in three years. In 2018, more than 50% of the operations (43) were performed, due to refitting of prototype, which involved prototype towing to port, deployment of elastomeric mooring tethers, integration of biradial air turbine, prototype redeployment and commissioning. In 2017 and 2019, 18 and 17 operations were registered respectively.

Figure 12 represents the operation distribution per month during the three years:

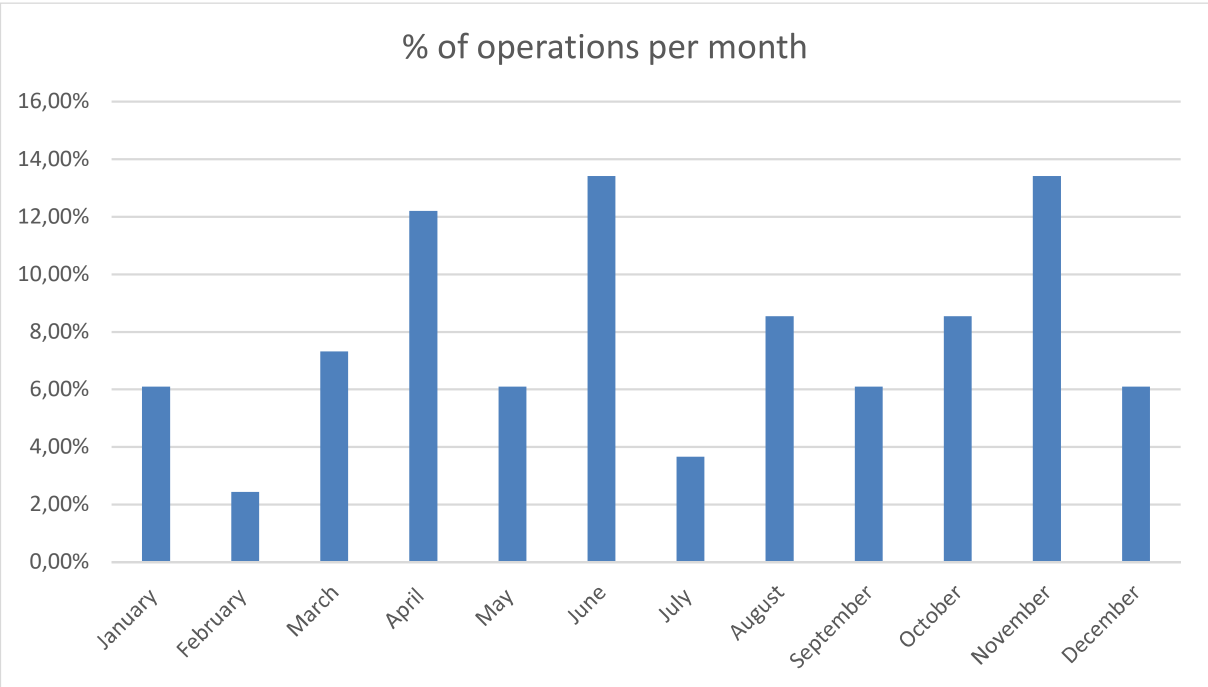


FIGURE 12 OPERATIONS PER MONTH DURING OPERA PROJECT

Comparing the distribution of operations with BiMEP's wave resource (Figure 13 and Figure 22), there is not a direct relation between the three months with best weather accessibility (June, July, August) and those with the highest activity (April, June and November). Only June is correlated. This is because many activities during the project have been related with the commissioning of the device and not with a specific O&M plan considering the weather conditions of the different seasons of the year.

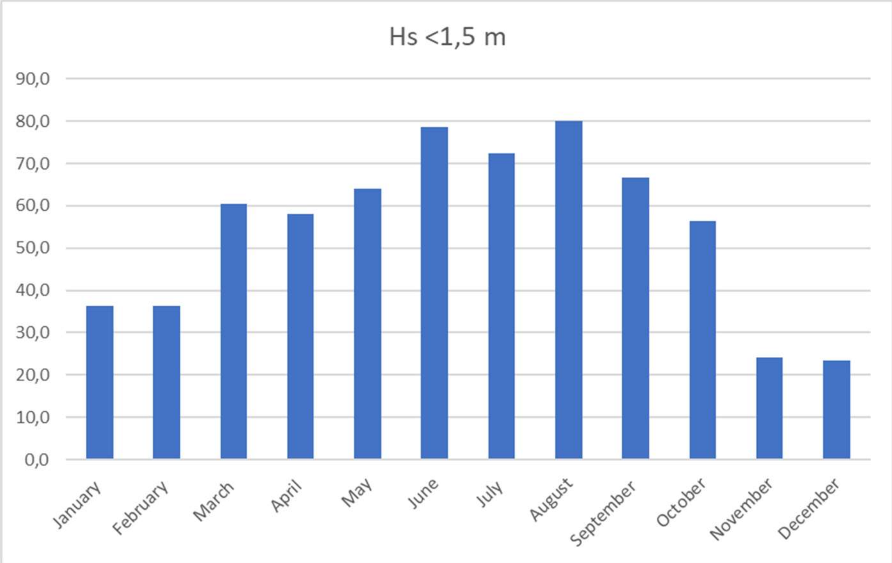


FIGURE 13 WAVE HEIGHT OCCURRENCE AT BIMEP (DATA OBTAINED FROM METEOCEAN BUOY FROM 20019 TO 2015)

In WP6, an OPEX model has been developed [11] where the different operations were grouped in 5 different groups (i.e. mooring, structure, control, electric-umbilical and PTO). Figure 14 shows the percentage distribution of operations per group and year, as well as the total during the project.

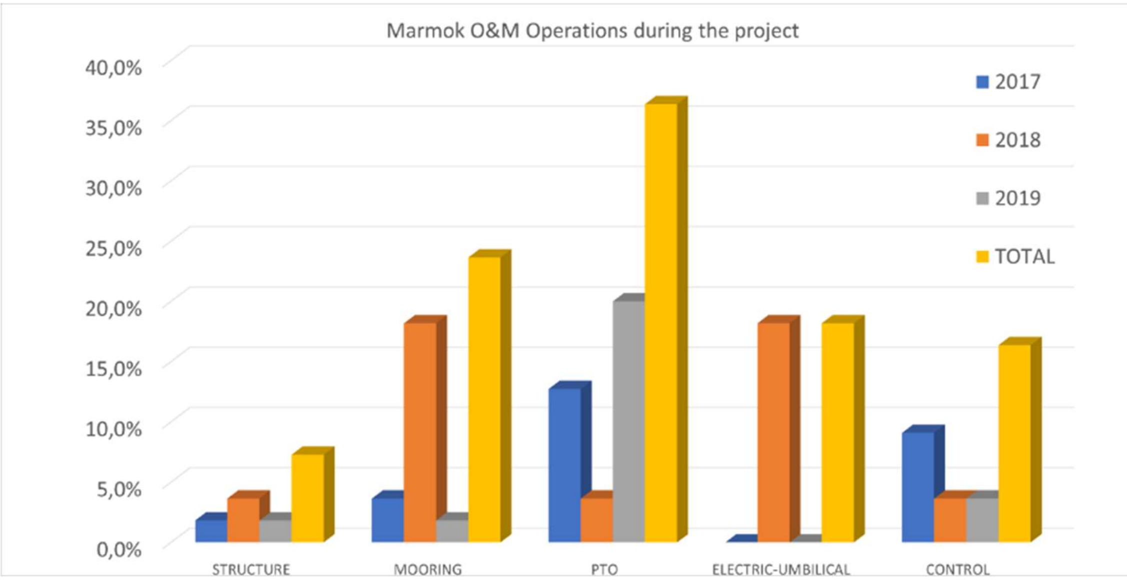


FIGURE 14 SUMMARY OF MARMOK-A-5 O&M OPERATIONS DURING OPERA PROJECT (2017-2019) GROUPED IN 5 GROUPS USED IN WP6 O&M MODEL

As it can be observed, the group with the highest O&M requirements has been the PTO. On the other hand, the structure required the minimum attention.

3.1.2 TOWING OPERATIONS

During the OPERA project, three towing operations have been completed. The first one in June 2018 (change-over), the second one in October 2018 (redeployment of refitted MARMOK-A-5) and the third one in June of 2019 (final decommissioning).

Next figures show some pictures of these operations.

FIGURE 15 CHANGE OVER MARMOK-A-5 14-15 JUNE 2018

Tow inside the Bilbao Port and River and load-in at NAVACEL facilities (15/06/2018)

FIGURE 16 CHANGE OVER MARMOK-A-5 15 JUNE 2018

Re-deployment at bimep (October 2018)

FIGURE 17 REDEPLOYMENT AT BIMEP 04 OCTOBER 2018

Main lessons learnt from these operations are as follows:

- Planning: be sure that all the involved parties are informed (check twice)
- Engineering: identify clearly the most risky/novel activities in the plan and focus on the contingency plans
- Preparation activities: perform tests/training before
- Execution: small delays can lead to a big delay (critical path)

3.2 ACCESS WEATHER CONDITIONS

The three years' experience of offshore operations has helped to establish a criterion to define an adequate **sea state** to carry out different types of operations. The experience has shown that not only is the maximum significant wave height (H_s) the single parameter to consider, but also wind conditions is another important parameter.

Figure 18, Figure 19 and Figure 20 present the upper extreme & quartile, median (|), mean (x), lower quartile and extreme per main group of operations regarding wave height, wind speed and peak period.

As we can observe, the PTO and control activities required a lower H_s and higher T_p on average. Essentially this is because the work inside the device requires more restrictive conditions. It is worth noting that wind conditions are directly related with short wave peak periods (T_p). Therefore, it is suggested a combined analysis of wave height and wave period in future work.

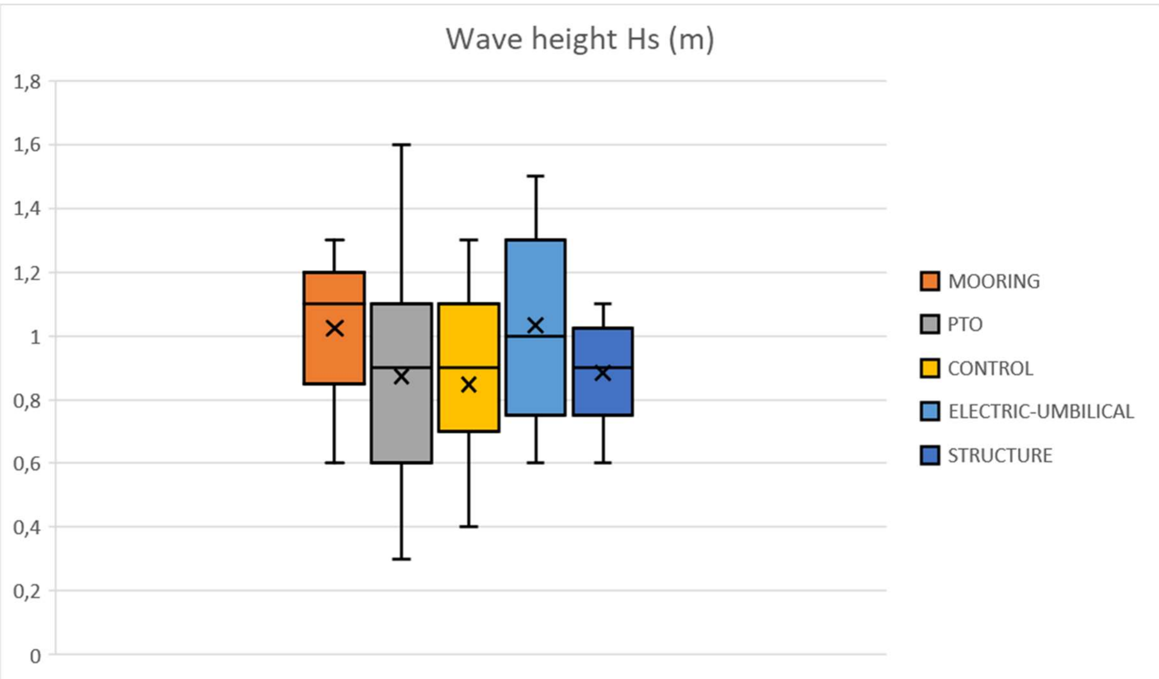


FIGURE 18 HS AVERAGE FOR STRUCTURE, MOORING, PTO, ELECTRIC-UMBILICAL, CONTROL

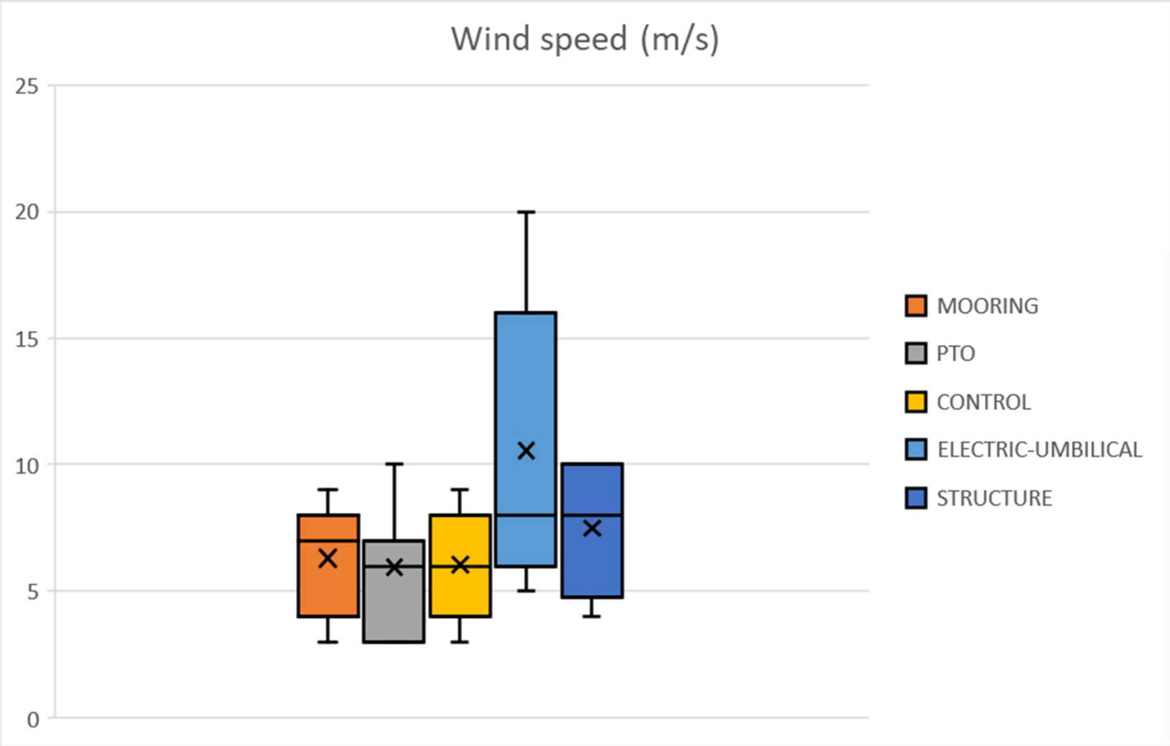


FIGURE 19 WIND SPEED AVERAGE FOR STRUCTURE, MOORING, PTO, ELECTRIC-UMBILICAL, CONTROL

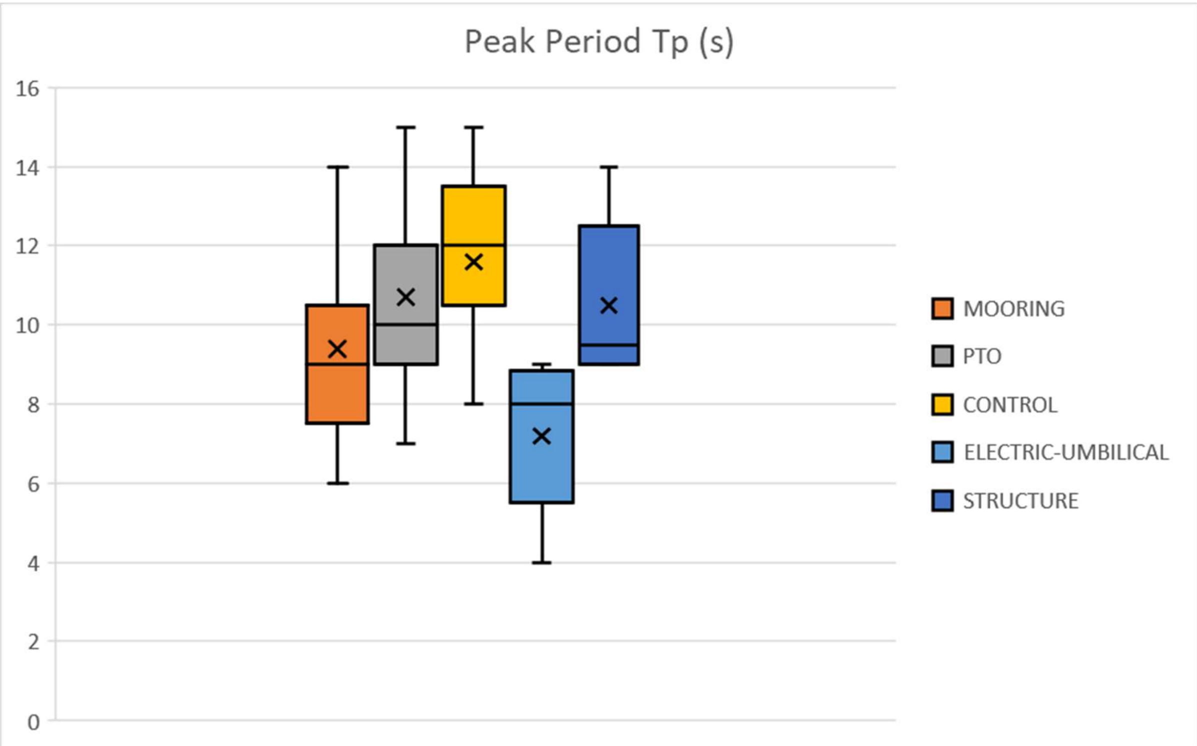


FIGURE 20 PEAK PERIOD AVERAGE FOR STRUCTURE, MOORING, PTO, ELECTRIC-UMBILICAL, CONTROL

Figure 21 shows the average wave peak period and the average wind speed for different O&M activities. Wind conditions directly influence access to the device.

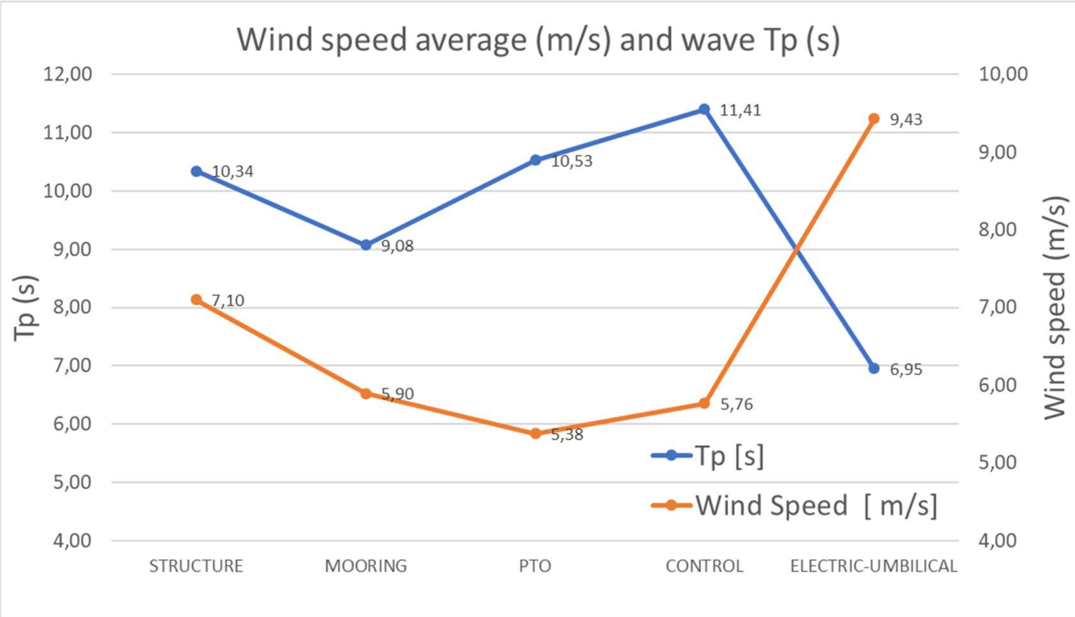


FIGURE 21 WIND SPEED AND WAVE PEAK PERIOD

When planning future O&M work, H_s and T_p restrictions should be also considered. Figure 22 shows the % of time per month H_s is lower from 1.5m and T_e greater than 8s ($T_p = T_e \cdot 1{,}12$ according to [12]).

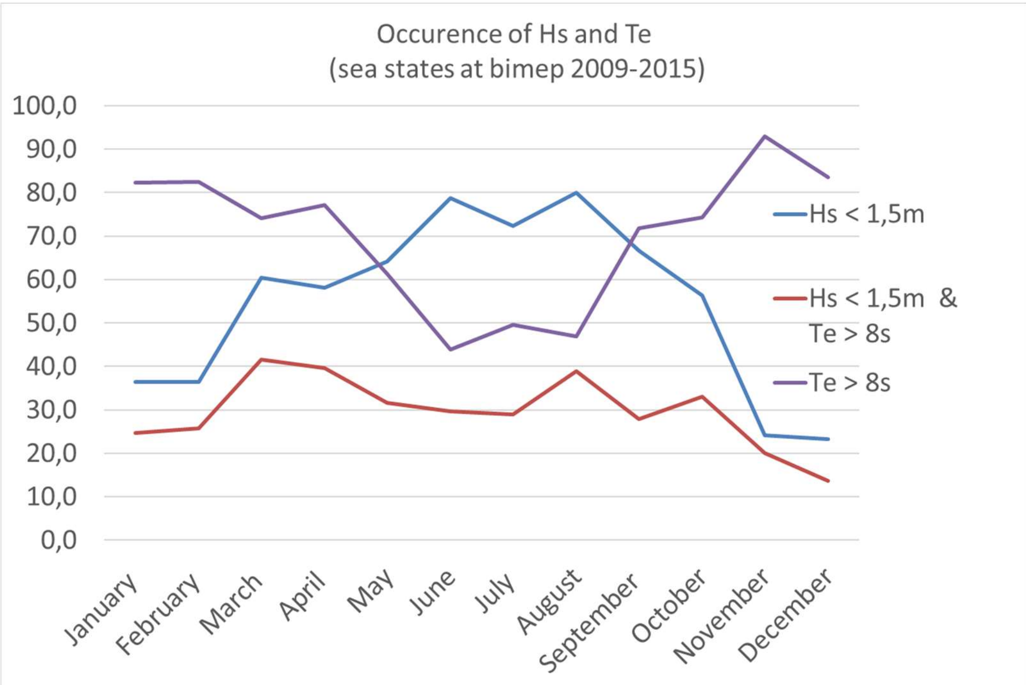


FIGURE 22 OCCURRENCE OF H_S AND T_E (BIMEP DATA 2009-2015)

This is just an indicative guidance. Further analysis should be done to obtain a more suitable correlation between wave and wind at BiMEP.

3.3 WORKING TIME

Next figure shows working time average per day for the different groups of operations. As with the previous figures, it presents the upper extreme & quartile, median (|), mean (x), lower quartile and extreme per main group of operations.

The duration is relatively similar (7-8 hours) for the Mooring, PTO, Control and Electric-umbilical. Unlikewise the towing operations (structure) require a longer duration.

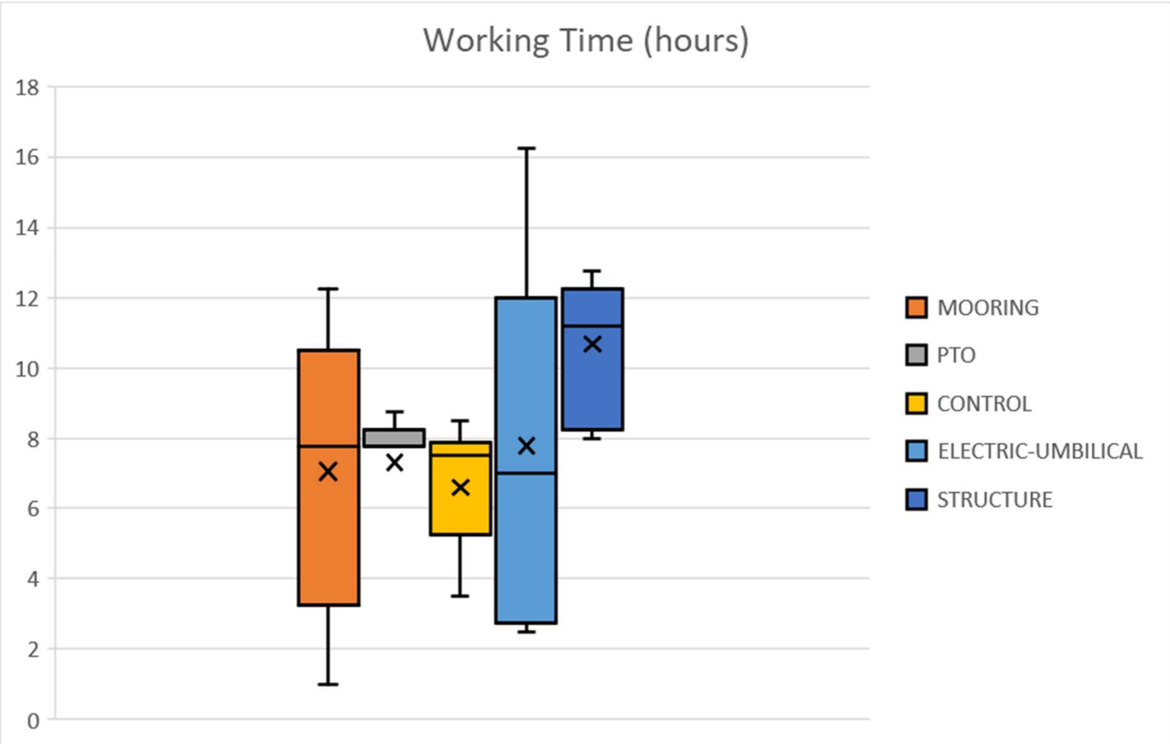


FIGURE 23 WORKING TIME AVERAGE FOR STRUCTURE, MOORING, PTO, ELECTRIC-UMBILICAL, CONTROL

3.4 OFFSHORE OPERATIONS ANALYSIS AND RECOMMENDATIONS

In this section real operations have been analysed with a view to reducing logistic time and associated equipment requirements thus resulting in a more cost-effective and risk-free solution that can be applied to other floating wave energy converters.

3.4.1 Analysis of Cost Reduction from the Offshore Operations

Deliverable D6.2 describes the operational model for a wave energy technology farm used in OPERA [11] . In this O&M model, 16 operations have been defined and clustered in five groups, namely mooring, structure, umbilical, control and PTO. Considering the average wave height and peak period for all the operations, the maximum threshold values for the first three groups of operations is H_s=1.3m and T_p=9s. In the case of operations inside the device (i.e. PTO and control), the average wave height and peak period are more restrictive. Actually, the lie around H_s=0.8 and T_p=10.8s. At the beginning of the project, a Hs of 1.5m was assumed for every offshore operation.

The **knowledge of component performance** has been reflected in the model with the uncertainty level and mean time between failures. Open-sea experience has permitted a better estimation of 11 operation parameters, which can translate into a 4% availability increase and 20% cost reduction compared with the initial version of the O&M model at the beginning of the project.

		Uncertainty level		Mean time between failures 1/years	
		After	Before	After	Before
Structure - Structural	Structural component	1	1	0,04	0,04
Structure - Structural	Inspection	1	2	0,5	1
Structure - Corrosion	All the structure	1	3	0,36	0,36
Mooring - Connector	Connector or polyester rope	1	1	1	0,4
Mooring - Buoys -Wire break	Mooring wear out	2	4	0,16	0,16
Mooring -Mechanical Failure	Mooring mechanic failure	2	4	0,0045	0,0045
PTO - Power Electronics	Power electronics	1	3	0,2	0,54
PTO - Generator	Generator, Mechanical components, Bearings	2	4	0,2	0,52
PTO - Turbine	Turbine, Blade	1	1	0,2	0,2
PTO - Valves	Valves	2	3	0,2	0,2
PTO - Global	Turbine / Back to back / Generator / bilge system	1	2	1,9	1,9
Electric - Umbilical	Umbilical degradation inspection	2	2	1	0,6
Electric - Umbilical	Cable	4	4	0,008	0,008
Electric - Umbilical	Replace element	2	3	0,2	0,2
CONTROL- Inspection	Inspection	1	2	2	1
CONTROL - Damage	Control & sensors / Protection function. Electric device problems	4	4	0,05	0,05

FIGURE 24 UNCERTAINTY LEVEL AND MEANTIME BETWEEN FAILURES AT THE BEGINNING VS END OF THE PROJECT

Next table presents a comparison between the OPEX model at the beginning and end of the project. As a result of increasing the number of preventive operations, availability slightly rises whilst corrective operations considerably decrease.

TABLE 2 OPEX MODEL COMPARISON AT THE BEGINNING OF THE PROJECT VS END OF THE PROJECT

Comparison of OPEX model	Number	Cost	Availability
Total operations	↓ 9%	↓ 20%	↑ 4%
Preventive operations	↑ 23%	↑ 5%	
Corrective operations	↓ 70%	↓ 70%	

The limited open-sea experience (three years) does not comprise the full diversity of lifetime operations and necessary **resources** to carry out them. Nonetheless, it contributes to improve the knowledge base for a better planning of future offshore operations. In which to ship selection for installation and decommissioning operations is concerned, for instance, important time savings can be obtained when using a bigger and specialized vessel. In this case, it could be completed in 2 days compared to 4-5 days using a smaller ship. The use of a bigger ships reduces the uncertainty level and the weather window waiting time but increases the vessel charter rate. The higher vessel charter rate somehow neutralizes final costs of these two distinct scenarios. Nevertheless, it might be recommended to use better ships as far as possible to improve the operation quality, provided the total costs are not penalized.

The experience from the offshore operations performed during the OPERA project points out that the availability of the device can be increased, and the operation costs reduced by **grouping compatible operations**. The typical operations that could be grouped are inspections since they can be planned (i.e. preventive maintenance) and focus on activities whose duration can be accurately quantified.

Figure 25 shows a percentage distribution of the initial O&M model at the beginning of the project, OPERA operations and final O&M model. It can be appreciated that despite 3 years is not so much time comparing with 25 years project life the information collected has been very useful for tuning the O&M model and reflects a realistic percentage of failures for the main groups of operations.

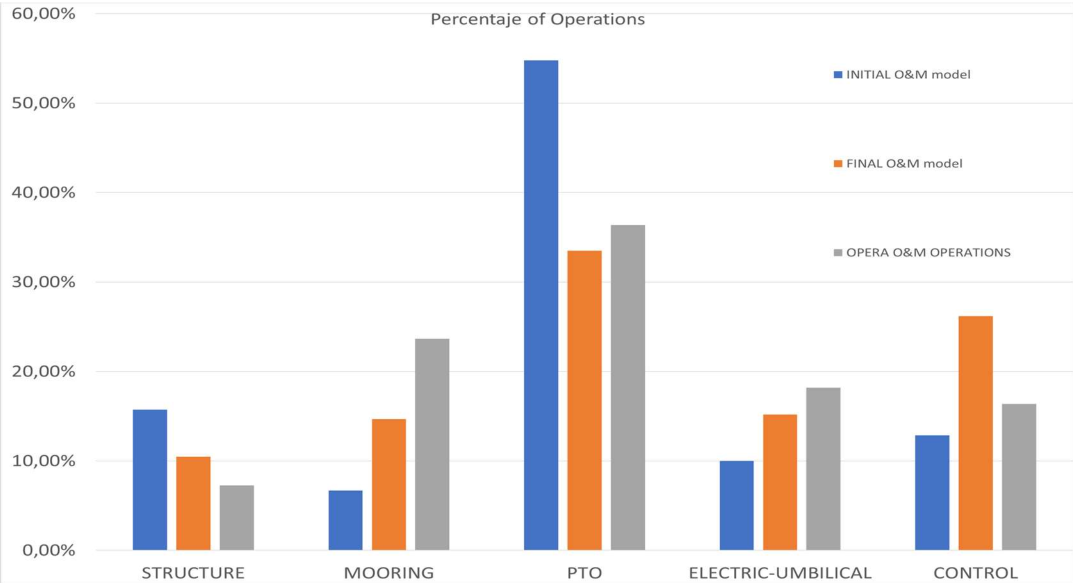


FIGURE 25 INITIAL O&M MODEL % OF OPERATIONS, FINAL MODEL AND OPERA OPERATIONS

3.4.2 De-risking Offshore Operations

The approach for risk assessment implemented in the OPERA project have been identified prior to commencement of the test programmed failure modes and survival scenarios (such as hull breach situations, mooring failure and power take off malfunction). The planning and execution of offshore operations have been continuously updated with this information and the reduction in uncertainties achieved from open sea implementation recorded to be used for final project assessment by WP7 entitled, "Risk management, cost of energy and final assessment". Although numerous sources of uncertainty and risks exist at the beginning of the project, the first tasks of WP7 focused specifically on:

- Risks arising from the innovative technologies used in the project
- Risks relating to the different phases of and activities performed during the life cycle of the OPERA technologies

Risks have been evaluated for the following technologies:

- Floating OWC (phases and activities) – Idom-OCEANTEC
- Advanced elastomeric mooring lines (cost-reducing innovation) – University of Exeter
- Bi-radial air turbine (cost-reducing innovation) – Kymaner

Note the OWC itself was not evaluated; Idom risk assessment was related to the implementation of the marine operations and other phases that were part of the project. Initial Risk Assessments was performed at the start of the Risk Management process and enabled decisions to be made on how best to treat risks and to identify when they have been mitigated to an acceptable level. The initial risk assessments have been reviewed by DNV GL, who have expertise in technical assessment, advisory and risk management, following recognised standards and practices.

In this section of the deliverable, a summary of the variations in the risks of the phases and activities will be presented.

Initially, 74 risks were identified and classified into the following groups of phases and activities (see Table 3).

TABLE 3 PHASES/ACTIVITIES CONSIDERED IN THE RISK ASSESSMENT

Phase	Activity
DESIGN	▸ BIMEP metocean conditions ▸ Loads on central tube ▸ Umbilical through Karratu
FABRICATION & ASSEMBLY	▸ Temporary supports
PRE-INSTALLATION	▸ Marking and sensing ▸ Surveys ▸ Instrumentation and tools
ASSEMBLY & INSTALLATION	▸ Mooring & Anchors ▸ Umbilical cable ▸ Wave device
OPERATIONS & MAINTENANCE	▸ Monitoring operations ▸ On-site O&M interventions ▸ Onshore O&M interventions
DECOMMISSIONING	▸ Wave instrument removal ▸ Umbilical and dynamic lines retrieval ▸ Wave device removal ▸ Foundations/anchors removal ▸ Site clearance and verification ▸ Material disposal

In the Deliverable D7.4 “Risk and uncertainty assessment and management for wave energy” ([13]), the risks assessment procedure, including the initial risk evaluation process and the risk management along the project. In the initial risk evaluation 74 risks were identified: 60 were considered as low, 13 as medium risk and only 1 was assessed as high. At the end of the project, all the risks have been re-evaluated, being 66 low, 6 medium and 2 high. Finally, these 74 risks were classified according to the following criteria:

- Those in which the risk has been reduced: 6
- Those in which the risk is the same <u>and</u> medium: 5
- Those in which the risk is higher <u>or</u> is still high: 3

4. HEALTH & SAFETY REGULATIONS APPLIED IN OPERA OPERATIONS

Wave energy devices are reaching a TRL where offshore testing is required. At present, this testing is done in accordance with existing offshore H&S standards, predominately aimed at the Oil and Gas industry, with some adaptions made for offshore wind, or onshore general regulatory framework. As the wave energy industry grows, modifications to the current standards will be required to make them relevant to the tasks conducted.

Existing standards and regulations for the offshore industry are in place with the principle aim of ensuring safety at sea, preventing injuries and avoiding damage to the environment. International offshore recommendations have been created since SOLAS was introduced in the aftermath of the Titanic disaster in 1912 and are regularly amended to include new developments and/or as a reaction to an unprecedented incident.

Marine Renewable Energy (MRE) devices are relatively new and have not yet been deployed commercially. Therefore, offshore operations abide by current offshore standards and regulations, most of which are adopted from experience within the oil and gas industry. Most of these are cross-disciplinary and are relevant to most offshore activities. However, some will either be irrelevant, over precautious or too lenient in relation to offshore operations for MRE devices. It should also be noted that most O&G installations are manned, and hence operational failures can cause greater risk to human life, whereas most WECs are independent structures.

Offshore operations are required for three project activities:

- Offshore surveys for planning and project development
- Installation and decommissioning of a MRE device/array
- Operation and Maintenance (O&M) of a device/array

This section will analyse the current standards and regulations for the offshore industry in regard to offshore installation and O&M operations, checking them against those applied for the installation of the OPERA OWC at the BiMEP testing site (see ANNEX I: STANDARDS FOR OFFSHORE OPERATIONS AT BiMEP for a complete set of standards gathered among different stakeholders operating at BiMEP). The applicability of the existing guidelines will be reviewed, particularly considering specific H&S requirements for renewables. For reference, a full list of operations as well as the regulations and standards considered during the installation process at BiMEP can be found in Deliverable D6.1 [14] .

The rules and regulations documented here are in no way exhaustive, and other legislation factors should come into consideration when undertaking offshore operations for MRE. However, with the lack of experience available in installing, maintaining and decommissioning a commercial WEC array it is advised that these regulations be followed wherever possible, and any alterations made are done so alongside a suitably detailed risk assessment and FMEA.

Once the industry has become more commercial, evidence will exist to indicate where regulations can be relaxed. However, it is understood that not all regulations are necessarily relevant for the deployment of test device hence, any required deviations from the recommended advice should be suitably justified by a Risk Assessment (RA), FMEA and continuous documentations of the procedures undertaken.

4.1 PRE-INSTALLATION PROCEDURES

To prevent a lengthy administration process for developers who wish to test their devices, the BiMEP testing facility have already obtained the necessary permits (Table 4). This is on the condition that the technology complies with the minimum technical requirements and is registered as a power generation facility [15] . Whilst these are not necessarily standards for operations conducted offshore, they detail the requirements for these processes to commence. For the installation of devices at other sites, the developers are required to obtain these permits themselves.

TABLE 4: BIMEP PRE-INSTALLATION PERMITS

Permit	Authority	Description
Resolución medioambiental (Environmental Impact Assessment)	Ministerio para la transición ecológica	Permit ensures that the project has no relevant impact on the environment
Autorización administrativa (Administrative Authorisation)	Ministerio de industria, Comercio y Turismo	Permits are requested to start-up any project of electric energy generation
Aprobación del Proyecto (Project Approval)		
Acta de puesta en marcha (Start-up Certificate)		
Ocupación del DPMT (Sea-Land public domain occupation)	Ministerio para la transición ecológica	Permit enable the exclusive occupation of a public domain
Informe de Marina Mercante (Merchant Navy Report)	Ministerio de Fomento	Report that the *Dirección General de Sostenibilidad de la Costa y el Mar* asks the Merchant Navy to provide before they give the *Sea-land public domain occupation* permit. This report assesses whether the activity affects the safety of other sea users.

4.2 GENERAL REGULATORY FRAMEWORK

All work operations are required to abide by a general regulatory framework, either onshore or offshore, to prevent injuries; assign responsibility; and to reduce risk as low as reasonably practicable (ALARP). Table 5 describes these regulations for various countries. The following sections review the existing guidelines, specifically considering potential H&S issues for MRE.

TABLE 5: GENERAL REGULATORY FRAMEWORK (LEANWIND DELIVERABLE 6.3 [16])

Country	Regulation	Year of implementation	Description
United Kingdom	H&S at Work etc. Act	1974	The main H&S legislation, and it designates responsibility of risk to those who create the risk. The main aim is to control risks ALARP. This act does not apply to marine operations
	Management of H&S at Work Regulations	1999	This act aims to improve the management of H&S by defining the duties of the employers and states that “suitable and sufficient” risk assessments should be conducted.
Denmark	Working Environment Act and cooperation at the workplace	1975	Main framework for governing occupational H&S. It mainly focuses on the design of the work place, working conditions and the safety of equipment used. It does not cover vessels or marine operations; however, it is applicable during the loading and unloading of a vessel at port.
	Offshore Safety Act	1981	Covers H&S for the offshore O&G industry whereby installations are located within Danish territorial waters.
	Renewable Energy Act	2008	Promotes the development of renewable energy. It does not specifically regulate occupational H&S but it does give authority to the Minister of Climate and Energy to implement new regulations.
Germany	Occupational H&S Act	1996	Main regulation governing occupational H&S and is a direct transposition of the EU Directive 89/391/EEC.
Norway	Working Environment Act	1977	Covers the conditions of employment and the working environment of employees but does not extend to working on a vessel. There is reference to the O&G industry, but it has not yet branched to include ORE.
Netherlands	Working Conditions Act	1999	Is the main Dutch legislation for H&S of employees, but it also covers those sailing under a Dutch flag. The Netherlands have already begun adapting regulations to suit ORE by implementing new regulations specifically for offshore wind. However, these regulations still have a way to go to cover all H&S aspects.

Country	Regulation	Year of implementation	Description
France	The Labour Code	1991	Legislation includes general responsibilities for employers, necessity of safety training, management of hazardous substances and specific safety measures; placing an emphasis on mitigating risks and the use of specific risk control measures.
Sweden	Working Environment Act	1978	Sets broad and general goals for ensuring a safe working environment for employees and states that the main responsibility for ensuring occupational H&S lies with the employer.

4.3 HEALTH AND SAFETY

Considering offshore operations, H&S regulations are generally developed for the Oil and Gas (O&G) industry. While they do not overrule the current regulations of the offshore industry, guidelines tailored towards the offshore wind industry are being created such as RenewableUK [17] , International Finance Corporation [18] , WindEurope [19] and Irish Wind Energy Association [20] . They aim to identify industry specific hazards and propose specific Risk Control Options (RCO's) to mitigate them, including the use of Personnel Protective Equipment (PPE) and appropriate training [16] .

This approach needs to be followed by the wave energy industry and is slowly being done e.g. BWEA [21] . This document identifies that where possible, offshore operations should be conducted during the summer months; where environmental conditions are better suited for installation and O&M activities. Furthermore, the sea temperature is greater and so risk is reduced in a man overboard scenario. O&M activities should preferably be planned preventive maintenance rather than reactive maintenance, to allow adequate planning time and to reduce risk. All activities should be conducted with appropriate risk assessments prior to the task and consideration be given to weather working limits, night working, PPE and emergency procedures.

The following table states the different safe work practices that should be considered during installation, O&M and decommissioning activities offshore; associated standards and regulations are discussed in the following chapters specifically considering the OPERA installation at BiMEP.

TABLE 6 SAFE WORKING PRACTICES THAT SHOULD BE CONSIDERED DURING THE LIFECYCLE OF AN OWF

Phases	Safe work practices
Installation Operation & Maintenance Decommissioning	Site Access and Navigational Safety
	Device Access and Egress
	Towing
	Diving
	Lifting
	Electrical Safety
	Personal Protective Equipment (PPE)

4.3.1 Site Access and Navigation Safety

BiMEP is a designated testing facility specifically for MRE situated 1.7km off the coast of Armintza, Basque Country, Spain. Other vessels are prohibited from entering the 5.3 km2 testing area to prevent damage to devices, electrical cables or moorings. Electrical cables outside this area are buried to prevent any potential damage [22] . The area is clearly delineated using seven marking buoys in accordance with maritime signposting regulations. All structures that are partially immersed are also marked by buoys in accordance with DNV-OS-H101 [23] and to prevent collisions at sea. The testing area has also been designed to avoid any conflict with vessels arriving and departing from the port of Armintza.

As previously mentioned, all devices should meet the minimum technological requirements as stated by BiMEP and the manager of the test site would have already gained the relevant permits required for installation at site. Additional attention should be paid to ensuring correct navigation signals and that the relevant authorities, including the relevant ports, have been notified of the installation activities and timetables.

4.3.2 Device Access and Egress

Accessing structures offshore is high risk and so all access to the OWC offshore during installation or O&M should be avoided if possible [24] . However, this activity may be necessary in the installation and O&M of the OPERA OWC. Figure 26, Figure 27, Figure 28 shows the accessibility to MARMOK-A-5 and BiMEP-I boat how is used to access to the device.

FIGURE 26 OCEANTEC-IDOM STAFF AT MARMOK A5

FIGURE 27 BIMEP I CLOSE TO MARMOK-A-5

FIGURE 28 BIMEP I AT ARMINTZA HARBOUR

Therefore, all access and egress routes between vessel and device should be “clearly marked, dry and clear of obstructions or trip hazards” as according to IMCA M202 – Guidance on the transfer of personnel to and from offshore vessels [25] . The environmental and safety limits are determined by the method of transfer (e.g.: gangway, personnel bucket, specialised vessel). Before any transfer is conducted a risk assessment must be in place, including rescue plans; the appropriate PPE must be worn; and safety gear must be on hand in case of a man over board [26] .

As the O&M requires personnel transfers between the OPERA OWC and whatever vessel that might be used for this purpose, the personnel was recommended to receive a Basic course on survival at sea and safe transfer to floating platforms, based on the standards stablished by the Global Wind Organisation and taught by the Comprehensive Maritime Safety Centre Jovellanos.

Besides, whenever personnel transfers are required, it is recommended that all standards should be abided by, environmental conditions considered, and a risk assessment completed.

4.3.3 Towing

The OWC was lifted by crane from port to sea level, ballasted, and towed to site using its mooring lines. The horizontal towing forces have been calculated for a series of tow speeds to show that the loads do not exceed minimum breaking loads for towing [27] or mooring line restrictions.

FIGURE 29 TOWING MARMOK A-5 NOVEMBER 2016

It should be checked that this procedure does not affect the tensile strength of the line for its mooring purposes. If the tensile strength is affected, an alternative line should be used for towing. The towline length should be determined by using the appropriate calculations in accordance with the bollard pull of the tow vessel and the minimum breaking load of the main towline; if the calculated towline length exceeds 200m suitable lighting should be applied to avoid collisions at sea [28] .

When under tow all crew should clear the deck area or stand in a safe position. All equipment should be continuously monitored and if any changes occur, they should be immediately reported to the master [29] .

Next figures show towing of MARMOK-A-5 device:

FIGURE 30 TOWING MARMOK-A-5 JUNE 2019

FIGURE 31 TOWING MARMOK-A-5 JUNE 2019

FIGURE 32 TOWING MARMOK-A-5 JUNE 2019

FIGURE 33 TOWING MARMOK-A-5 JUNE 2019

4.3.4 Diving Activities

Diving operations are required for the following offshore activities:

- Installation, repositioning, inspections and O&M of the mooring and the static electrical cable protection devices;
- Opening and closing of the valve of the ballast system.

The diving operations undertaken during the installation of the OPERA OWC abided by two different sets of standards. The first, Boletín Oficial del Estado (BOE) [30] [31] , is the official state newsletter of Spain that states the national diving regulations. BOE give detailed restrictions and working limits for all underwater activities within Spanish jurisdiction.

These state specific limitations on diving work days, such as a maximum 9 hour working day with a total immersion limit of 3 hours, and a minimum team of four, all of whom require the necessary qualifications and valid medical certificates. The second is the International Marine Contractors Associations (IMCA) [32] . These focus more on the suitable design and testing of equipment and the qualifications (IMCA D 26/01) [33] and medical fitness of the dive crew (IMCA D 07/17) [34] . The comparable Irish (S.I. No. 422/1981 – Safety in Industry (Diving Operations) Regulations, 1981) [35] and UK (HSE The Diving at Work Regulations No. 2776 1997) [36] standards are more stringent with the minimum required team members (5 team members for surface supply dives) and are comparable with qualification and medical fitness. However, they do not give specific limitations on the workday but rather request that the risk assessment for the project is referred to. Specific duration limits are only stated for closed bell system dives, of which it is assumed will not be required for the operations detailed here.

FIGURE 34 DIVING ACTIVITIES AT BIMEP

It is therefore assumed that the operations undertaken during the installation of the OPERA OWC abided by the most stringent regulations, which include quantitative limits. In order to effectively compare these to the alternative standards discussed here, a risk assessment should be completed and compared with the aforementioned restrictions. At present, it is viewed that these stringent regulations are the most suitable in regard to ensuring safety at sea to both personnel and the environment. Figure 34 shows an example of diving activity at BiMEP.

4.3.5 Lifting

Two cranes are used from the dock for lifting operations. Figure 35 shows a lifting activity of MARMOK-A-5.

FIGURE 35 LIFTING MARMOK-A-5 NOVEMBER 2016

Lifting operations, onshore and offshore, must abide to the standards as highlighted in DNV-OS-H205 [37] . All cranes should be in good working order, accompanied by the necessary certificates and the crane vessel should comply with the requirements outlined in DNV-OS-H101 [23] . The crane should be manned by an appropriately trained and certified crew member within the working and environmental limits of the crane and vessel. Figure 36 shows a lifting activity of MARMOK-A-5 (June of 2019).

FIGURE 36 LIFTING MARMOK-A-5 JUNE 2019

The appropriate calculations must be undertaken before commencing a lift procedure to ensure that the device is under control at all times and to avoid yawing and/or pendulum motions. A minimum of 3m clearance should be ensured between the lifted object and the lifting equipment/obstructions during the lifting process.

4.3.6 Personal Protective Equipment

Prior risk assessment should ensure that all personnel have and are designated by their employer the correct PPE for their tasks. Whilst not applicable to offshore work, it is recommended that the appropriate standards in the Personal Protective Equipment at Work Regulations SI 1992 No. 2966 [38] are adhered to. Appropriate training should be provided for all designated PPE, and it should be kept in good condition to reduce risks [39] . Appropriate seafaring PPE is listed in the following table.

TABLE 7 TYPES OF PPE FOR SEAFARERSC [40]

Type	Examples
Head Protection	Safety helmets, bump caps, hair protection
Hearing Protection	Earmuffs, earplugs
Face and eye protection	Goggles and glasses, facial shields
Respiratory protective equipment	Dust masks, respirators, breathing apparatus
Hand and foot protection	Gloves, safety boots and shoes
Body Protection	Safety suits, safety belts, harnesses, aprons, high visibility clothing
Protection against drowning	Life jackets, buoyancy aids and lifebuoys
Protection against hypothermia	Immersion suits and anti-exposure suits

It should be noted that PPE does not reduce the risk of a hazard occurring, but rather reduces the risk of injury if a hazard does occur.

4.4 VESSEL MANNING & COMPETENCY ASSURANCE

4.4.1 Vessel Manning

Different types of vessels are required for the different stages of each process, and the relevant documents must be available according to the relevant regulations and standards. According to the STCW Code 1978, all vessels over 500 GT should hold a safe manning document which ensure that the vessels have a suitable number of crew to adequately complete assigned tasks, these crew members are required to be fully qualified and competent at their task [41] , hold a valid medical and fitness certificate and wear appropriate PPE [42] . Furthermore, the UK MCA in MSN 1868 recommends that all vessels less than 500 GT should also abide by these regulations.

The main purpose of vessel manning regulations is to ensure that the vessel is “sufficiently, effectively and efficiently manned to provide safety and security of the ship, safe navigations and operations at sea, …prevention of human injury or loss of life, …and to ensure the welfare and health of seafarers through the avoidance of fatigue” [43] . In this respect, all seafarers must be fully qualified to undertake their proposed tasks and have certificates proving training has been undertaken [44] . All vessels must be manning adequately to provide sufficient crew to ensure the safety of the vessel and personnel in addition to those required to undertake proposed operations safely. All seafarers have a maximum workday of 14 hours [45] hence allowing a minimum of 10 hours rest in every 24 hours [46] , this may only be adjusted in emergencies.

4.4.2 Vessel Assurance

For each offshore activity a vessel must be selected that is "suitable for all its planned tasks", if there are any doubts in this matter it is suggested by DNV-OS-H101 [23] that an independent suitability survey is undertaken. Only the multi-purpose workboat Aitana B [47] , that could be suitable for several offshore operations, has been analysed in regard to the suitable standards and regulations. However, all the vessels used in offshore activities such as the AHT for mooring placements, CLV for securely laying cables and barges or tugs for transporting devices should abide by the same quality of standards. Several factors – such as operation limits, deck space, crane capacity and personnel limits – should be considered for the selection of an economically efficient vessel that is suitable for its assigned task and designated site.

In terms of vessels, all those undertaking offshore operations should be fitted with the appropriate GPS and AIS equipment in relation to their size and activities in order to avoid collisions [48] and to allow for the adequate monitoring of marine traffic [49] .

Each vessel over 500 gross tonnes is required to comply with the ISM or ISPS codes, and compliance is recommended but not mandatory for those below this. Each utilised vessel must have the relevant valid certificates for operation and for any planned operations and must have had an "IMCA Audit" to ensure these are complete. Internationally, all vessels must abide by the rules and regulations of their flag state, no matter the activities and all vessels must abide by the relevant bylaws of the local authority.

Bureau Veritas (BV) designates specific classifications for vessels with dynamic positioning (DP) capabilities. This multi-purpose workboat is equipped with the most basic form of DP system (DYNAPOS SAM) and is DP class 1 [50] , which means that with a single component failure the loss of position may occur [51] , and that position keeping needs to be maintained manually by the Dynamic Positioning Operator (DPO).

According to the [52] and DNVGL [53] the following operations must adhere to the recommended DP classes (Table 6). All diving operations will require a vessel with an IMO DP class 2 or class 3 to minimise human error to maintain position and hence no single failure will prevent the recovery of the divers. Any vessel undergoing crane operations, or the offshore transfer of personnel are also advised to have an IMO DP class 2 or class 3. Position keeping is vital during these operations, and no single failure should incur contact between the vessel, lift, object or OWC. These requirements are especially prevalent for device hook up – for both installation and maintenance – as it will require both divers and cranes for the dry-mate connection, and for the load shackle cable system (LSCS) which is installed by a dive team. Additionally, ballasting of the OWC during upending should not adversely affect the position keeping of the vessel.

A failure modes and effects analysis (FMEA) should be kept up to date for the DP system and records maintained on board the vessel; whilst this is not necessary for DP class 1 systems it remains recommended. Hence, it should be considered whether the Aitana B complied with the standards described above if an on-board crane was used or personnel transferred to the OWC whilst offshore. It may be the case that for the trial OWC deployment, a single failure that would cause the loss of position to a vessel below 500 GT would not have incurred any danger or injury to human life. However, the recommendations stated above should be considered for any future operations.

TABLE 8 HIERARCHY OF REQUIREMENTS FOR DP VESSELS AS ESTABLISHED IN THE IMO GUIDELINES [54]

DP Class	Description
DP Class 1	Loss of position may occur in the event of a single fault
DP Class 2	A loss of position does not occur in the event of a single fault in any active component or systems. Normally static components will not be considered to fail where adequate protection from damage is demonstrated and reliability is to the satisfaction of the Administration.
DP Class 3	For equipment class 3, a single failure includes: 1. Items listed above for class 2, and any normally static component is assumed to fail. 2. All components in any one watertight compartment, from fire or flooding. 3. All components in any one fire sub-division, from fire or flooding

5. SUMMARY OF LESSONS LEARNED FROM OFFSHORE PARTICIPANTS

The lessons learned developed in this chapter, came from two workshops (one internal and other external) and from exchange of practical experiences between partners. The two workshops have been hosted during the project lifetime. In the first one, open-sea operation was discussed at the Bilbao Marine Energy Week 2017. In fact, the workshop was aimed at learning from the first practical experiences of open-sea operation, identifying common challenges, best practices and needs. This workshop brought together technology and project developers, marine contractors and test sites/pilot projects as catalysers of experience generation [55] . The participants of this workshop were:

- Mr Carlos López Pavón, Project Manager. CoreMarine [56]
- Dr Sarah Thomas, Head of R&D. Floating Power Plant [57]
- Prof Tony Lewis, Chief Technical Officer. OceanEnergy [58]
- Mr Borja de Miguel Para, R&D Engineer. Idom-Oceantec [2] [3]

The second workshop was hosted at Tecnalia in May 2019 co-organised by BiMEP and Tecnalia. The objective was to elicit lessons learnt from offshore operations directly related to the installation and maintenance of MARMOK-A-5 device (including moorings and umbilical). The following participants attended:

- Tecnalia: Joseba López Mendía, Pablo Ruiz-Minguela, Raúl Rodríguez Arias [59]
- BiMEP: Yago Torre-Enciso, Dorleta Marina [60]
- IDOM: Patxi Etxaniz, Borja de Miguel, Endika Aldaiturriaga
- CoreMarine: Carlos López Pavón, Goren Aguirre
- CDA: Luis Martínez Cerecedo, Marcos Giordano [61]

The following subsections present the main conclusions drawn from the workshops.

5.1 PLANNING OF OPERATIONS

Detailed planning of operations is paramount for avoiding any risks and uncertainties at sea. It is therefore strongly recommended:

- Do extensive testing and simulations prior performing the operations.
- In the case of critical or bespoke components, a mock-up for demonstrating the handling and installation of the component would be recommended, and whenever it is possible to have spare material.
- Perform a risk analysis using standard tools and procedures (HAZIP, HAZOP, etc.)
- Account for delays in your schedule.
- Have an alternative Plan B if the operation cannot be finished in time.

- Engage with all people involved in the different operations. Listen to their feedback, they provide valuable information to solve problems that may arise during the execution phase.
- Onshore meetings save valuable time offshore.
- Visual aids such as work cards, use of different colours and graphical diagrams to prevent any misunderstanding at sea.

FIGURE 37 DEMONSTRATION OF THE INSTALLATION OF THE LOAD SHACKLES WITH A WOODEN MOCK-UP

5.2 DATA ACQUISITION

Regarding data acquisition, processing and its use afterwards, the following ideas have been collected:

- Build sensor redundancy since it is not easy to spot errors in the instruments at the moment.
- Have a back-up and contingency plans should anything fails.
- Different ways of measuring the same parameter should be implemented as a way for comparing and spotting errors
- Ensure the sampling frequency of sensors is not too low for the intended use.
    - Assess when data is good or bad. Check if sensors measurements are correct.
    - Analyse the data as soon as possible. Do not wait one year to realise it was not good enough.
- Measurements are important, but integration of these measurements into the monitoring system is not that straightforward. Prepare for failure of communication cables.
- Plan for the use of data. A huge amount of data is collected per day.

5.3 ECOLOGIST CONCERNS

Regarding ecologist concerns the panellists highlighted:

- Early consultation with local community.
- Carry out environmental impact studies.
- Monitor deployment to gain more information.
- In regions without much industry these projects can attract international interest, which is great for the economy.

5.4 RECOMMENDATIONS

A final set of various recommendations was commented by panellists:

- Perform a staged testing programme.
- Document everything. Changes to the prototype should be logged very carefully using any kind of media such as videos and photos, because one year later you will not remember the change made.
- If no regulation exists, do not to take O&G regulations as baseline since they are based on very different requirements.
- Allow for mistakes since mistakes most certainly will happen and have sufficient resources to deal with problems.

5.5 METEOROLOGICAL CONDITIONS

Meteorological conditions are fundamental to successfully complete an offshore operation, and because of that we must pay special attention to it.

5.5.1 Weather Forecast

It is very important to have a weather forecast from different sources (Windguru [62] , Metocean Forecast provided by BiMEP [63]) and then contrast with real time data [64] . The accuracy of forecasting decreases with time and therefore it is extremely important to check daily forecasts to adjust the planning of offshore operations. Moreover, visual inspection of the sea the same day of the operation together with experience of the boat captain is equally important.

There were three different sources of real time sea conditions data at BiMEP:

- Wavescan buoy Fugro-Oceanor [65]
- Zunibal, Anteia buoys [66]
- Tri-Axys buoy (OPERA project) [67]

In the framework of TRL+ project a metocean analysis [15] of BiMEP was carried out with the purpose of describing and characterization of the metocean conditions at BiMEP test site. Wind, wave, current and sea level conditions have been characterized to be considered in a design process or marine operations at BiMEP.

5.5.2 Tide Influence

The tides have an important effect on the harbour because the water depth could vary till 5 meters in specific seasons[4] . During the project some harbour operations have been influenced due unsuitable tides timetable.

On the other hand, the effect of the tides has not been decisive, but it has influenced in the work of some operations of divers. The current pushes the device in a certain position and affects the divers specially in “freeswiming” style operations. For example, in the umbilical recovery operation, the positioning of the boat was very important and had an influence on the timetable of the operation.

The strongest tides at BiMEP occur in autumn, especially in September. The most significative effect of tides occurs at half tide (see next figure example).

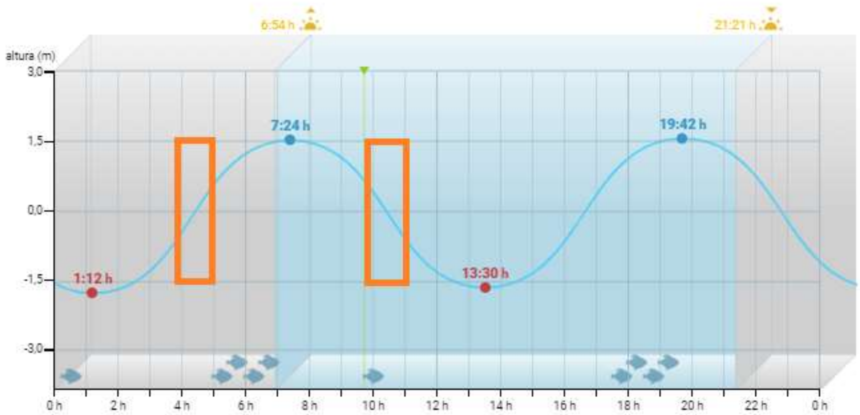


FIGURE 38 EXAMPLE OF TIDAL CYCLE

5.5.3 Wind Influence

Wind has an important influence on marine operations. During the OPERA project it has been confirmed that wind can affect marine operations, especially for divers, MARMOK-A-5 access and ship operations. An OPEX model [11] has been developed in OPERA where the weather windows have been considered with the maximum wave height. Drawing from the experience gained in the project, wind speed is proposed to be considered in the weather window estimation.

5.5.4 Safety in the Operations

It is necessary to define a procedure for decision making whether an operation can be performed in a safe manner. According to the table below, on board work can be considered the most restrictive operation in terms of Hs, T_p and wind speed (a small T_p is related with wind waves). In the Douglas sea scale, these operations required a smooth sea state (level 2), as they were performed with Hs between 0.8 m and 1 m and T_p between 7.19 s and 10.59 s.

TABLE 9 DOUGLAS SEA SCALE, ALSO CALLED THE "INTERNATIONAL SEA AND SWELL SCALE"

Degree	Height (m)	Description
0	0–0.10	Calm (Glassy)
1	0.10–0.50	Calm (rippled)
2	0.50–1.25	Smooth
3	1.25–2.50	Slight
4	2.50–4.00	Moderate
5	4.00–6.00	Rough
6	6.00–9.00	Very rough
7	9.00–14.00	High
8	14.00+	Very high
9	0–0.10	Phenomena

Wind speed ranged 2.5 and 5.5 m/s, according to Beaufort wind scale Maximum of “Gentle Breeze” conditions, level 3.

TABLE 10 BEAUFORT WIND SCALE

Degree	Description	speed (m/s)
0	Calm	<0.3
1	Light Air	0.3–1.5
2	Light Breeze	1.6–3.3
3	Gentle Breeze	3.4–5.5
4	Moderate Breeze	5.5–7.9
5	Fresh Breeze	8.0–10.7
6	Strong Breeze	10.8–13.8
7	Near Gale	13.9–17.1
8	Gale	17.2–20.7
9	Strong Gale	20.8–24.4
10	Calm	<0.3
11	Light Air	0.3–1.5
12	Light Breeze	1.6–3.3

Currently, BiMEP does not request a maintenance plan for devices. However, a plan of basic actions focused on ensuring device integrity could be included as a requirement. With time, BiMEP could give a feedback to users according to past experience.

5.6 COMBINED OPERATIONS

In what to combination of operations is concerned, some benefits can be obtained provided things are planned well. At the end of the project it has been shown that, with good planning, the combination of operations could be carried out successfully.

One important issue for combined operations is to involve divers in the planning phase, since there are operations that require significant physical effort. Moreover, the type of operations should be evaluated, as it may be difficult to accomplish two complex operations in a row. Because of that, sufficient time slack should be considered to account for unforeseen events.

5.7 RESOURCES

In order to carry out certain operations, it has been identified that medium-sized vessels would help to reduce the costs of large ships and be able to complete operations with more safety than with small sized ships.

Tug boats with open stern in the port of Bilbao would improve the availability of means for future users of BiMEP.

5.8 O&M

The following conclusions have been obtained from the people directly involved in the O&M of the MARMOK-A-5 device:

- The dexterity of the master has a direct influence on the access to the device, throughout the project it has been improved in the accesses to the device.
- The lifeline for access has been discarded, replacing it with a double hook.
- The possibility of including two access stairs to the device to use one or the other depending on the conditions and redundancy issues is contemplated.
- The periodic use of the crane is recommended in such a way that it does not degrade due to the adverse conditions of the sea that cause it to deteriorate due to disuse.
- For future designs, it is proposed to have a diesel engine to be able to use the crane in case of power failure to the device and a longer arm.
- A lateral line was included in the second deployment so that the access boat can be moored.

5.8.1 Preventive Maintenance: fouling

- It has been verified that the month of the year in which there is more fouling is in September (at the end of summer), for that reason, it is a good time to perform tasks for removing fouling since beyond September the access weather windows decrease significantly. For example, in the case of Karratu, fouling has made inspection tasks more difficult, so a periodic cleaning is recommendable to inspect the important points of the anchoring of the device.

- The paint coating applied to MARMOK-A-5 performed well. From the first to the second year there was not much marine growth; from the second to the third year, there was some growth of fouling in MARMOK-A-5. After the second decommissioning at the end of OPERA project a fouling study was proposed.
- Marine growth in tethers has accumulated less than in polyester lines. Mussels take time to stick, but once building-up starts, the growth becomes exponential.

5.8.2 Supply requirements in operations

- Careful planning is needed regarding supply requirements for each operation. Enough spare supplies should be carried for replacement so that it does not prevent from finishing the operation. It is necessary to limit the possibility that low-cost supplies mean not being able to carry out an operation (e.g. ropes, pulleys, compressors, shackles, pins, air hoses, fittings ...). For example, different sections of wire were purchased for the Karratu.
- It must be evaluated the risk and consequences of lacking supplies that need to be purchased for an operation (example: compressor hose for decommissioning of MARMOK-A-5).
- The delivery lead time of spare parts must be evaluated to take a decision on potential storage requirements.

5.8.3 Marine Operations and O&M

It is very important to consider marine operations and O&M in the design of the ocean energy device. Offshore operations introduce further requirements into the device design:

- Take into account available equipment and resources in the area.
- Design for availability, installability and maintenance; not just for efficiency and cost.
- Build some flexibility into the design of the prototype.
- Fouling in mooring lines is not normally taken into account when calculating mooring forces on the device. Besides, marine fouling is very difficult to predict.
- Scaling up the device can make impossible to use the same solution either technically (high loads) or economically (O&G technologies or vessels).
- Plan for WEC accessibility due to resonance in some sea states.

5.9 EXPERIENCE OF WAVE SENSORS AT BiMEP AND MUTRIKU

In this subsection, it will be summarised the experience gained along the OPERA project in relation with the offshore operations for the installation, O&M and decommissioning of the wave sensors in the two test sites (BiMEP and Mutriku).

At BiMEP, a wave rider buoy purchased to AXYS was installed around 200m in the North-West direction from the MARMOK-A-5 device. The buoy was commissioned in December 2016 and has been since inspected on-site and maintained. The list of the main interventions on the buoy is:

- Planned maintenance of the buoy and inspection of the mooring (29/09/2017).
- Recovery from the site due to an electronic failure (05/10/2017).
- Reparation in the Tecnalia laboratory and preparation of the mooring line for the winter season (09/01/2018).
- The buoy was re-deployed wet-towed (14/03/2018).
- After almost one year in continuous operation it was necessary to change the batteries and update the firmware (onshore). Final deployment on board a small boat (26/02/2019).
- The TRIAXYS buoy was finally decommissioned by the end of the OPERA Project (10/07/2019).

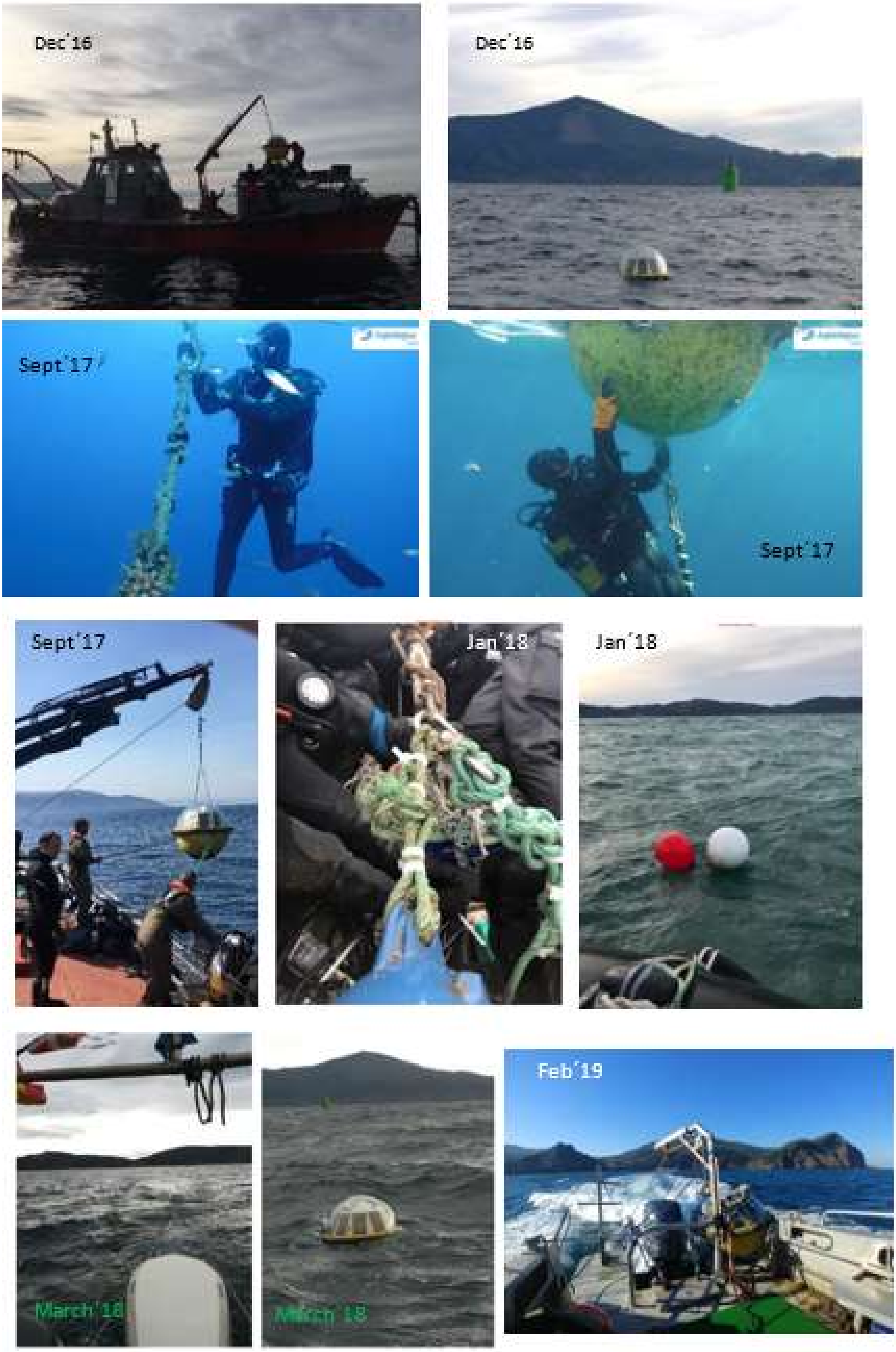


FIGURE 39 SUMMARY OF THE MARINE OPERATIONS ON THE WAVE RIDER BUOY AT BIMEP

The lessons learnt are:

- Whenever possible, avoid repairs offshore specially for the first time and if there is not a technician from the manufacturer present.
- Technical training on-shore.
- Check that your assets offshore are ready for the winter season.
- In the second deployment, a more efficient and cost saving procedure was followed (wet-towed with a RIB instead lifting down with a crane from a multipurpose boat).
- The final deployment was the most cost-effective.

For Mutriku testing, two different wave (pressure) sensors were installed. The first one, the RBR VIRTUOSO is an offline pressure sensor installed around 200m off the testing chamber inside the Mutriku wave power plant. This sensor was installed over a concrete sub-base on the sea bottom in October 2017.

FIGURE 40 OFF-LINE PRESSURE SENSOR INSTALLED IN FRONT OF THE MUTRIKU WAVER POWER PLANT

During the winter in 2018, a storm the sub-base and supporting bolts and it was necessary to repair it and reinstalled the VIRTUOSO. In parallel, it was decided to install an on-line pressure sensor with direct communication with the chamber, with the following drawbacks:

- Long permit delays.
- The operation was planned for summer with excellent visibility and ideal conditions. Deployment in shallow waters between 6 and 12 meters, where waves affect the seabed.
- To complete the operation, 3 days where needed. Incidentally, the operation was delayed by several months. It was performed between the end of the summer and winter, with suboptimal environmental conditions. Although the operation was successfully carried out, working conditions inside the camera were rather complicated.

FIGURE 41 REINSTALLATION OF THE PRESSURE SENSOR AND INSTALLATION OF THE ON-LINE SENSOR AT MUTRIKU

The lessons learnt are as follows:

- Consider some extra slack in your planning for administrative permissions
- Equipment in the wave breaking zone are exposed to high loads so a high number of repairs/substitutions could be expected.

5.10 MOORING INSTALLATION

- A lot of practical learning was obtained for the handling of chains in port from the first line and this learning could be applied to the others.

- A large AHV vessel (e.g. Union Bear) is quite expensive compared to a Multicat, but it allows significant time savings. While a Multicat limits one single mooring line to be installed per day and trip, an AHV vessel can install 3 lines on one day.

5.11 INSTALLATION AND DECOMMISSIONING

- The lack of understanding with the tugboat master delayed device removal, which entailed an additional cost.
- Due to this fact, it is proposed to have planning meetings with the tugboat owners (whenever possible) before the operation to improve the coordination of manoeuvre.
- The crane company is not responsible for the shackles attached to the crane and does not offer it, so a guild coordinator must be responsible for linking the different operations.
- There are limited resources for towing at the entrance to port since there is only one enterprise authorized to complete this operation.
- Thanks to the learning of the first commissioning, the second has been carried out in a much safer way.
- It is proposed to better define the chain of responsibility in supplies.

5.11.1 Karratu

- From the first manoeuvres to the last ones, significant improvements have been obtained in terms of operation time.
- For designing future Karratu mooring configurations, the operations to be carried out will be considered.
- There have been no problems with the nodes under the mooring pennant buoys.
- The mooring surface buoys move a lot, half a meter away the buoy moves the node.
- Periodic maintenance: cleaning of mussels to consider.
- Mooring loads monitoring: complex design of communication cables prone to failure. There are some wireless communication systems that could be used.

5.11.2 Connection of the Static and Dynamic Cable

- It has been identified the need to improve the connection-disconnection of the umbilical with the static cable since it implies an extremely high cost. At EMEC, they have connectors and direct connections. There are developers who use multi-connectors.
- The connection of the umbilical with the WEC is complicated for the divers, so it is proposed to involve divers during the design phase of future prototypes.
- It is proposed to improve the design of the boat landing.

5.12 COSTS

When planning a WEC test campaign, it is necessary to start with an in-depth knowledge of the test site and the conditions that are likely to be encountered [61] . This will enable proper design of both the device and all related operations. It is also important to anticipate anything that might happen during all the project phases, with a rigorous risk analysis which evolves apace with the project itself. Finally, it is vital to make a proper evaluation of the cost all of this will involve, in order to prevent minor mishaps from putting paid to complex operations. To make sure this is the case, it is particularly advisable to make a generous allowance for all the contingencies that will inevitably arise, however painstakingly the whole project has been prepared and reviewed.

In order to illustrate the costs of a sea trial, let us assume a test duration of one or two years. This figure is relevant to determining the design load set as per IEC TS 62600-2:2016, and hence the costs of the mooring. Next table shows an example of costs presented by BiMEP at ICOE 2018 [68] .

TABLE 11 GLOBAL ESTIMATION OF COSTS BY BIMEP FOR GENERIC PROJECTS DURING THE TEST PHASE [68]

Item	Before trial (k€)	During trial (k€)	After trial (k€)
Test site fee		250,000	
Acquisition of mooring	250,000		
Umbilical cable	50,000		
Connection, cables and connectors	80,000		80,000
Installation of mooring system	100,000		50,000
Ship for laying umbilical cable and connection	20,000		20,000
CL insurance for power connection	20,000		20,000
CL insurance for trial		40,000	
Towing and mooring of device	12,000		6,000
Diving operations and supervision	5,000		5,000
Visits and inspections		7,000	
Travel and subsistence costs		36,000	
Contingencies		100,000	
TOTAL	**537,000**	**433,000**	**181,000**

6. CONCLUSIONS

During OPERA project more than 90 offshore operations have been performed in three years. In 2018 more than 50% (43) of the operations where performed, almost 20 in 2017 and a similar number in the first half of 2019.

General conclusions

- There is not a direct relation between the three months with the best weather accessibility (June, July, August) and the three months with highest activity (April, June and November). Only June is correlated. This is because many activities during the project lifetime have been related with the commissioning of the device and not determined by the O&M plan which would take into account the weather conditions in the different seasons of the year.
- In order to define a more detailed O&M time schedule, more years of experience ought to be accumulated.
- Out of five different groups of operations included in OPEX model, the PTO is the group accounting for the highest number of operations.
- The three years' experience of offshore operations has helped to establish a practical criterion to define a suitable sea state to carry out the different types of operations. The experience has shown that not only is the maximum significant wave height (H_s) the parameter to consider, but also wind conditions. It is worth noting that short wave peak periods (T_p) are directly related with wind conditions in the area.
- PTO and control activities required a lower H_s and higher T_p on average. Essentially this is because the work inside the device requires more restrictive conditions. It is suggested as future work to perform a combined analysis of H_s and T_p.
- No injuries have been reported along the offshore operations in the OPERA project. Therefore, the main principle of SAFETY FIRST have been achieved. On the top of this, no loss of any assets (i.e. WEC, mooring tethers or biradial turbine) have occurred during the offshore operations.

Cost reduction for offshore operations

- Real operations have been analysed with a view to reducing logistic time and associated equipment requirements thus resulting in a more cost-effective and risk-free solution that can be applied to other floating wave energy converters.
- The greater knowledge of component performance has been reflected in the final O&M model by means of a lower uncertainty level or a longer mean time between failures. Open-sea experience has permitted a better estimation of 11 operational parameters. They translated into a 4% availability increase and a 20% cost reduction compared with the initial version of the O&M model at the beginning of the project.

- The limited open-sea experience (three years) does not comprise the full diversity of lifetime operations and necessary resources to carry them out. Nonetheless, it contributes to improve the knowledge base for a better planning of future offshore operations.
- The experience from the offshore operations performed during OPERA points out that the availability of the device can be increased, and the operation costs reduced by grouping compatible operations. The typical operations that could be grouped are inspections since they can be planned (i.e. preventive maintenance) and focus on activities whose duration can be accurately quantified.
- Despite three years is a relative short time compared with a 25-year project lifetime, the information collected has been very useful for tuning the O&M model. It reflects a realistic percentage of failures per main group of operations.

Health and safety

- Current standards and regulations for the offshore industry in regard to offshore installation and O&M operations have been analysed, checking them against those applied for the installation of the OPERA OWC at the BiMEP testing site.
- The applicability of the existing guidelines will be reviewed, particularly considering specific H&S requirements for renewables. For reference, a full list of operations as well as the regulations and standards considered during the installation process at BiMEP can be found in Deliverable 6.1.

Lessons learned from offshore participants

- Lessons learned from offshore participants have been documented. They come from two workshops hosted during the project lifetime as well as from partners' exchange of practical experiences.
- Practical guidance is gathered for the future planning of operations, data acquisition, meteorological conditions, grouping of operations, O&M recommendations, mooring and costs.

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8. ANNEX I: STANDARDS FOR OFFSHORE OPERATIONS AT BIMEP

TABLE 12: THE DOCUMENTS AND ASSOCIATED STANDARDS HELD BY THE COMPANIES CONDUCTING OFFSHORE OPERATIONS

COMPANY	ROL	ACTIVITY	GOOD PRACTICES/ DOCUMENTS REQUIRED	LAW/STANDARD
AZTI	R&D	Environmental monitoring	Auditory on Occupational Health and Safety Management System	Chapter IV of Spanish Law 31/95 on the Prevention of Occupational Hazards
				Royal Decree 39/1997 (Regulation of Prevention Services)
			Certificate of the Health and Safety Management System	OHSAS 18001
GMSM	SURVEILLANCE AND EMERGENCY RESPONSE OF THE TEST SITE	Maritime Surveillance	Certificate of navigation for ships of less than 24m length	
			Certificate of Safety for ships of less than 16m length	Order of the 10th of June 1983, about Complementary Rules modified by the Order of the 21st of January 1986 and the Order of the 29th of August 1986
			Maritime Register	STCW Code 1978
			Vessel Classification certificate	STCW Code 1978 DNV-OS-H101 General Marine Operations
			Hull insurance	STCW Code 1978
			Ship's crew trained in: basic seamanship and specialised survival	STCW Code 1978
			Minimum ship's crew certificate	STCW Code 1978
ZUMAIA OFFSHORE	MARINE CONTRACTOR	Marine operations	Vessel fact sheet	STCW Code 1978. DNV-OS-H101 General Marine Operations
			Vessel Classification certificate	STCW Code 1978. DNV-OS-H101 General Marine Operations
			Equipment and auxiliaries (including fire - fighting pumps) Maintenance historical	DNV-OS-H101 General Marine Operations
			Maritime Register	STCW Code 1978
			Minimum ship's crew certificate	STCW Code 1978

COMPANY	ROL	ACTIVITY	GOOD PRACTICES/ DOCUMENTS REQUIRED	LAW/STANDARD
			DP Plot, DP Manual, DP trails	IMO MSC Circ.645 "Guidelines for Vessels with Dynamic Positioning Systems". In conjunction with implementation of paragraph 4.12 of the 1989 MODU Code as amended.
			Common Marine Inspection document	International Marine Contractors Association (IMCA)
			Lifting gear certificates	DNV-OS-H205 Lifting Operations. DNV-OS-H101 General Marine Operations
			Fire control and safety plan	DNV-OS-H101 General Marine Operations
			Safety equipment certificates	DNV-OS-H101 General Marine Operations
			Muster list	DNV-OS-H101 General Marine Operations
			Safety inductions	STCW Code 1978
			Safety drills and planning & record	STCW Code 1978
			Risk assessment method systems	HSE Information sheet: Guidance in Risk Assessment for Offshore Installations, No.3/2006
			Hull insurance	STCW Code 1978
			Civil Liability Insurance	STCW Code 1978
			STCW95 qualification of the ship's crew	STCW Code 1978
CDA	MARINE CONTRACTOR / DIVER	Marine operations	Safety regulations for underwater activities should be governed.	BOE núm. 280, de 22 de noviembre de 1997. Normas de seguridad para el ejercicio de actividades subacuáticas.
			Guideline for diving operations - safely and efficiently	IMCA (D 014) international marine contractors association
			Diving Equipment Systems Inspection	IMCA D 023 Diving Equipment Systems Inspection Guidance Note (DESIGN) for surface orientated (air) diving systems
			Saturation diving systems	IMCA D 024 DESIGN for saturation (bell) diving systems
			Surface supplied mixed gas diving systems	IMCA D 037 DESIGN for surface supplied mixed gas diving systems

COMPANY	ROL	ACTIVITY	GOOD PRACTICES/ DOCUMENTS REQUIRED	LAW/STANDARD
			Mobile/portable surface supplied systems	IMCA D 040 DESIGN for mobile/portable surface supplied systems
			Hyperbaric reception facility (HRF) forming part of a hyperbaric evacuation system (HES)	IMCA D 053 DESIGN for the hyperbaric reception facility (HRF) forming part of a hyperbaric evacuation system (HES)
			Diver Certification	IMCA D 26/01 – Competence assessment of experienced surface supplied divers
				IMCA D 07/17 Diver training certificates – IMCA acceptance criteria
			Commercial Diver Certification. Responsibilities, qualifications and certifications of diving staff.	ADCI association of diving contractor international
BAJO EL AGUA	MARINE CONTRACTOR / DIVER	Marine operations	Safety rules in underwater activities	BOE Num 264, de 1 de noviembre 2016. Convenio colectivo de buceo profesional y medios hiperbáricos y el acuerdo sobre Normas de seguridad en actividades subacuáticas.
			Vessel Classification on List 5	Sea captaincy Regulations