PALM
Quick Connection System

WES Quick Connection Systems Stage 2
Public Report

Apollo Offshore Engineering Ltd.

This project has been supported by Wave Energy Scotland

1 Project Introduction

Apollo developed the Pull and Lock Marine (PALM) connector in Stage 1 of the development process and were successful in progressing to Stage 2. Stage 1 focused on high-level concept development activities and on proving the PALM's feasibility against the QCS Impacts. Stage 2 has seen the concept refined and adapted in the context of two test case implementations of the PALM on actual wave energy converter (WEC) designs.

The primary test case for Stage 2 has been Mocean's Blue X device, which includes a combined mechanical and electrical connection mounted underneath the WEC.

The alternative test case for Carnegie's CETO 6 device has been fundamentally different, with a mechanical seabed-mounted connection that experiences much higher mechanical loads but does not include electrical connection.

2 Description of Project Technology

The components making up the primary test case's PALM connector are shown in Figure 1.

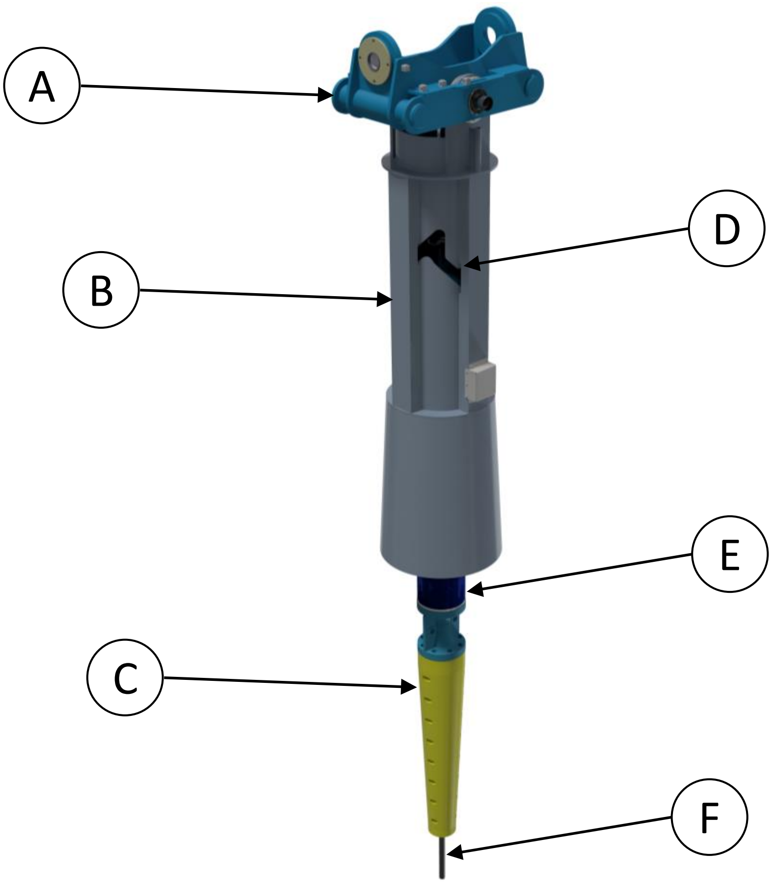

Figure 1 - System overview

A	Cradle	D	Plug (hidden by receptacle)
B	Receptacle	E	Mooring node
C	Bend stiffener	F	Electrical cable

3 Scope of Work

3.1 Primary test case – Mocean Blue X

The Mocean Blue X utility-scale attenuator device, see Figure 1, is being built for the WES Novel WEC Stage 3 Project. The Blue X is a hinged raft with a unique geometry that improves performance by up to 300 percent compared to traditional hinged rafts and increases survivability by diving through the largest waves.

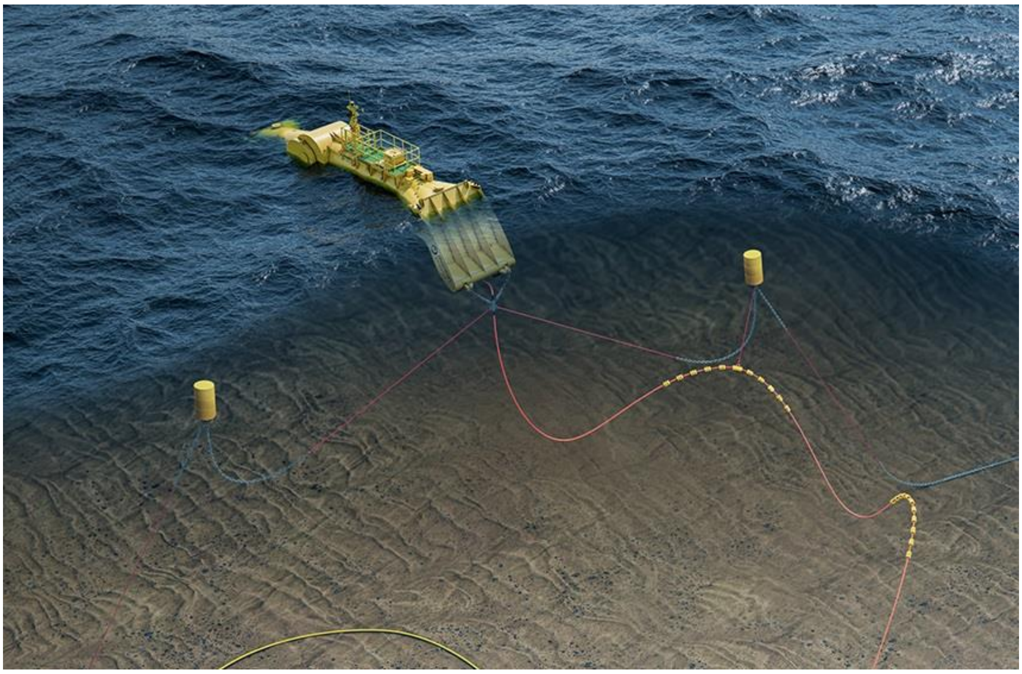

Figure 2 - Mocean Blue X baseline mooring configuration

Figure 3 and Figure 4 illustrate how the PALM has been integrated onto the WEC. The mid-hull position was selected in consultation with Mocean (as opposed to the hull tip connection in the baseline scenario). This location effectively removes the wave channel from the mooring load path, so that its design can be optimised purely for its primary hydrodynamic purposes.

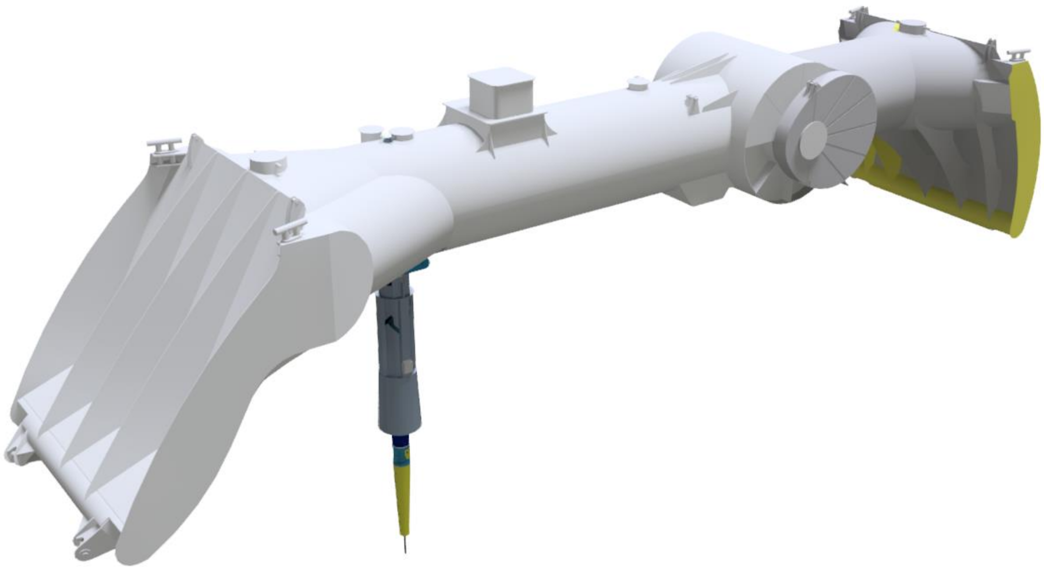

Figure 3 - PALM integration (1)

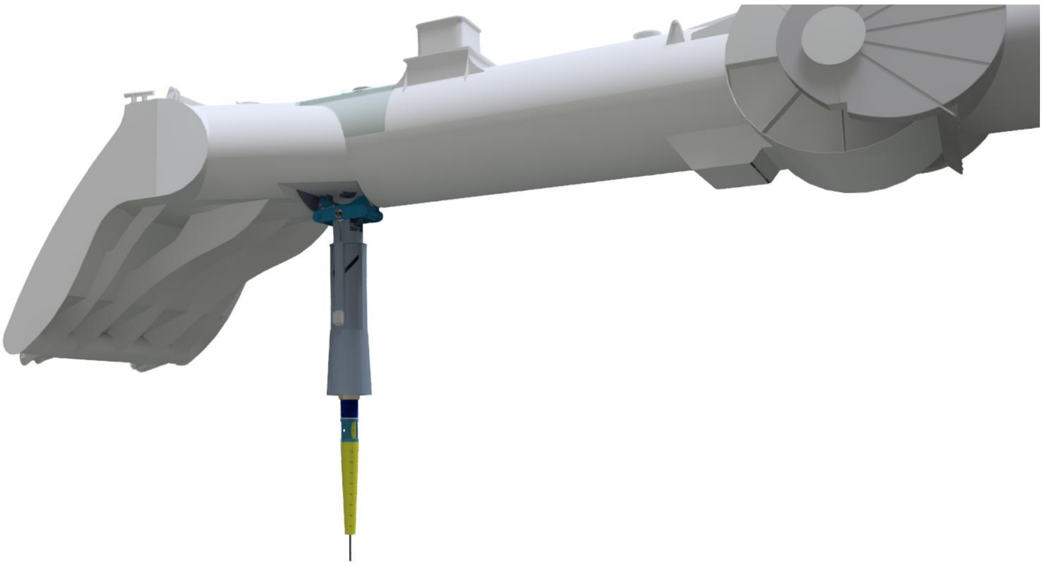

Figure 4 - PALM integration (2)

3.2 Alternate test case – Carnegie CETO 6

The Carnegie CETO 6 Multi Moored (C6M), see Figure 5, is a point absorber WEC comprising a submerged Buoyant Actuator (BA) that sits below the water surface and oscillates with wave and current. Orbital motion of the BA activates a belt and pulley that drives a power take-off system to convert mechanical energy into electricity.

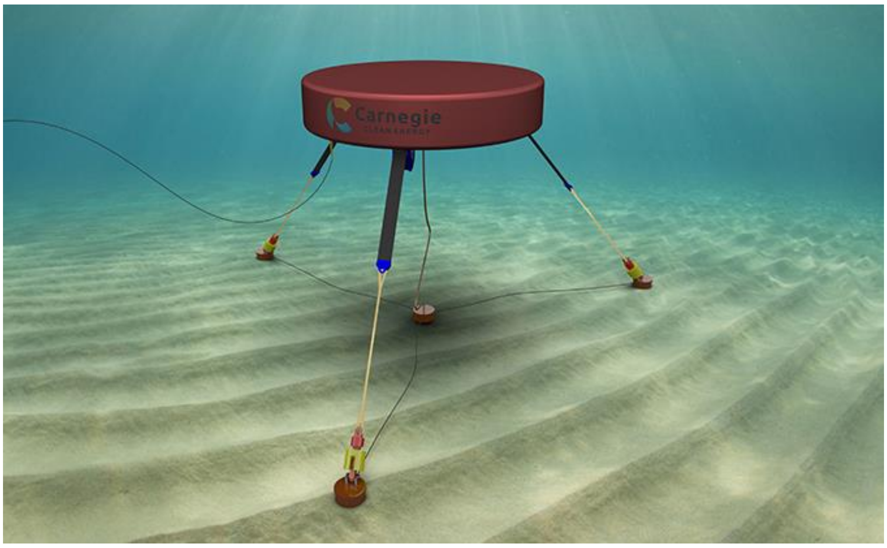

Figure 5 - Carnegie C6M mooring arrangement

The components making up the alternate test case's PALM connector are shown in **Error! Reference source not found.**.

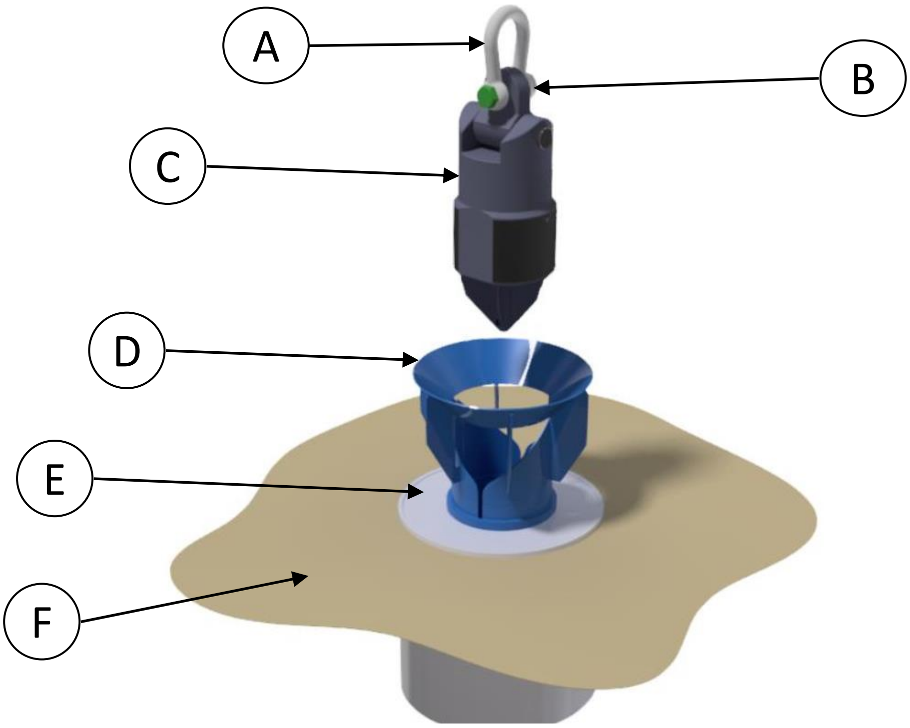

Figure 6 - System overview

A	Shackle	D	Receptacle
B	Lifting yoke	E	Foundation structure
C	Plug	F	Seabed

For the QCS case, the PALM replaces the connectors and hinges at the seabed, as the baseline arrangement shows in Figure 5. The plug is connected to the end of the mooring line and the receptacle is fixed to the anchor pile.

3.3 Engineering and design activities

Apollo's PALM QCS technology has been adapted to suit each of the above WECs. The process for this design integration is summarised below:

1. Information gathering.

Device geometry, mooring details, device loads and motions, electrical requirements, environmental data, and deployment site information.

2. Basis of design document creation.

Definition of the quantifiable constraints that would inform the design development.

3. Conceptual design development in Autodesk Inventor.

Iterative process to determine how best to integrate the PALM QCS to the devices, how to arrange the necessary mechanical and electrical components, hinges etc.

4. Mechanical and structural engineering analyses.

Classical hand calculations and FE analysis of the designed components.

5. Survival and operational mooring analyses.

Modelling of the WEC/PALM/mooring system in Orcaflex to determine the survival load cases for the design, examine the operability in a range of environmental conditions, and to establish to what extent the implementation of the PALM has an impact on power generation.

6. Electrical system specification.

Selection of wet mate connectors and slip rings – note this is for the primary test case only; the alternative test case design is a purely mechanical connector.

7. Operational methodology creation.

Definition of the discrete tasks involved in connecting and disconnecting the WEC from its moorings and electrical export cable.

8. Technical design review and operational risk assessment.

Comprising full internal and external audits of the design details and operational methodology in the form of FMECAs and HIRAs.

9. Commercialisation study

Review of CAPEX and OPEX for the devices within a strategy for commercialisation of the PALM.

Detailed information on the above activities can be found in the documents listed in Table 1.

4 Project Achievements

4.1 Design Evolution

The primary philosophy of simplicity and robustness for the marine environment remain at the forefront of the team's intentions with regards to the design. As design detail and scrutiny has increased, so too has the number of parts in both test case designs; this is inevitable to some degree as the program progresses towards detailed design and prototype manufacture. In any case, efforts have been made to minimise this increased complexity, while relying on the same connection principle that avoids actuated moving parts. This can be seen in the evolution of certain geometrical aspects between the primary and alternate test cases. Notably, the yaw alignment mechanism has been improved and simplified. A new load transfer detail has been introduced which is viewed as a more elegant solution in previous configurations and which will be carried over into future iterations of the primary test case design.

4.2 Performance against target outcomes

The team set out to complete a FEED-level design development project. The appropriate level of detail has been deemed to have been successfully achieved. This is reflected in the level of detail shown in the designs, and the associated engineering analyses. Suitably robust engineering checks have informed the design, which has in turn informed the cost estimates.

Survivability has been demonstrated through engineering design calculations based on a variety of environmental and operational loading conditions. Global loads and motions have been developed through the survival mooring analyses of the WECs with the mooring systems in Orcaflex. These loads and motions have informed the mechanical design and structural strength assessments of the PALM components.

Operability of the system has been assessed by simulating the functions of connect and disconnect through the limiting environmental conditions. Loads and motions at various stages of operations have been derived. These results in turn became inputs for the mechanical design. The limiting environmental conditions were used to develop an annual percentage availability of the system.

Impact on device energy capture has been assessed quantitatively through analysis in the primary test case, and by inspection for the alternate test case. For the primary, the system was analysed in Mocean's energy yield simulation model and found to have minimal impact. For the alternate test case, the modification to the baseline mooring architecture is so minimal that it is clear there will be minimal impact on energy yield.

5 Recommendations for Further Work

Considerable design detail and engineering scrutiny has been applied to the development of the PALM across the two test cases during Stage 2. Significant progress has been made since Stage 1 by adapting the PALM concept to suit the specific requirements of the two cases for defined locations.

An overview of the anticipated physical testing scope for Stage 3 is defined in D111. The commercialization report (D93) sets out the strategic plan for bringing the PALM to market.

6 Communications and Publicity Activity

Generally, Apollo have avoided widespread publicity of the concept while it continues to go through research and development, progressing its TRL status. Ongoing work with IP specialists and development of commercialisation strategies will inform future publicity activity.

Selected confidential conversations have been held with 3rd parties who expressed interest in applications of the PALM to their proprietary equipment, covering floating offshore wind and tidal power devices, also anchor pile manufacturers.

The PALM has also been introduced to a project funded by the Offshore Wind Growth Partnership in which it is being assessed for a weather-vaning FOW hull form.

The PALM was presented in the June 2020 issue of the biannual newsletter published by the Aberdeen Renewable Energy Group:

https://www.aberdeenrenewables.com/wp-content/uploads/2020/06/AREG_Newsletter_FinalVersion_Prepared_by_BIG_04.06.20.pdf

7 Useful References and Additional Data

A comprehensive suite of design, analysis, risk assessment, and commercial deliverables were produced over the course of the Stage 2 project. These are listed in Table 1.

Table 1 Apollo Stage 2 deliverables

Reference	Title	
[1]	D21 Basis of design	308-002-8001RPT
[2]	D22 Project metrics	308-002-8002RPT
[3]	D34 Design review report	308-002-8003RPT
[4]	D35 Performance impact report	308-002-8023RPT
[5]	D41 Survival mooring report	308-002-8004RPT
[6]	D42 Mechanical design report	308-002-8005RPT
[7]	D43 Structural interface report	308-002-8006RPT
[8]	D44 Electrical specification	308-002-9001SPE
[9]	D51 Operational methodology report	308-002-8007RPT
[10]	D53 Operability analysis report	308-002-8008RPT
[11]	D61 FMECA report	308-002-8009RPT
[12]	D62 HIRA report	308-002-6003RPT
[13]	D72 GA drawings (alt)	308-002-8600GA to 8602GA
[14]	D73 Survival mooring report (alt)	308-002-8011RPT
[15]	D75 Design review report (alt)	308-002-8013RPT
[16]	D76 Performance impact report (alt)	308-002-8014RPT
[17]	D81 Operational methodology report (alt)	308-002-8015RPT
[18]	D82 Storyboards (alt)	308-002-8501DD to 8504DD
[19]	D83 Operability analysis report (alt)	308-002-8016RPT
[20]	D84 FMECA report (alt)	308-002-8017RPT
[21]	D85 HIRA report (alt)	308-002-6005HAZ
[22]	D91 Cost model (primary)	308-002-0001RPT
[23]	D92 Cost model (alternate)	308-002-0002RPT
[24]	D93 Commercialization report	308-002-0003RPT
[25]	D104 Project risk register	308-002-0001REG
[26]	D111 Stage outline test plan	308-002-8022RPT