ORCADES MARINE
Management Consultants Ltd

Third Party Verification Report
Wello Oy

Wello
DIRECT CONVERSION

"Penguin" Wave Energy Converter
Installation at EMEC
Wave Test Site, Billia Croo

Document Number OP 212.001

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Table of Contents

Table of Abbreviations	
ALS	Accidental Limit State
BP	Bollard Pull
CD	Chart Datum
CHA	Competent Harbour Authority
DHSE Rep	Designated Health and Safety Representative
DSA	Dynamic Systems Analysis
EMEC	European Marine Energy Centre
ERP	Emergency Response Plan
ETA	Estimated time of arrival
HAT	Highest Astronomical Tide
HIRA	Hazard Identification and Risk Assessment
HSE	Health and Safety Executive
IMO	International Maritime Organisation
ISM	International Safety Management Code
KN	Kilo Newtons
KW	Kilo Watt
LAT	Lowest Astronomical Tide
LOLER	Lifting Operations and Lifting Equipment Regulations 1998
MAIB	Marine Accident Investigation Branch
MBL	Minimum Breaking Load
MCA	Maritime and Coastguard Agency
MHWN	Mean High Water Neaps
MLWN	Mean Low water Neaps
MHWS	Mean High Water Springs
MLWS	Mean Low Water Springs
MWS	Marine Warranty Surveyor
m/s	Metres per second
NRA	Navigation Risk Assessment
OMMC	Orcades Marine Management Consultants Ltd
PTW	Permit to Work
PPE	Personal Protective Equipment
RA	Risk Assessment
RHIB	Rigid Hull Inflatable Boat
RIDDOR	Reporting Injuries & Diseases & Dangerous Occurrences Regulations 1995
ROV	Remotely Operated Vehicle
SWL	Safe Working Load
TSB	Test Support Buoy
TSS	Traffic Separation Scheme
ULS	Ultimate Limit State
WEC	Wave Energy Converter
WLL	Working Load Limit

1 Introduction

The Penguin is installed at the EMEC wave test site Berth 1 at Billia Croo. Orcades Marine have been requested to provide the Third Party Verification of the device structure and connections to the moorings. The Penguin was installed early in March 2017 and commissioning was completed by 31st March 2017. The Penguin has remained on location for just over a year without suffering any apparent damage or any degradation in performance.

2 Executive Summary

This statement provides a summary of the scope of work to which Third Party Verification has been applied and the conclusions that have been reached. The details of the conditions, limitations and assumptions that apply are listed in Section 5. This report is valid for a deployment of 12 months' duration on Berth 1 at the EMEC Billia Croo site provided the Penguin device, its moorings and structure remain substantially unchanged, and frequent monitoring and regular inspection is continued throughout.

Environmental conditions

The environmental conditions used as the basis of the design of the mooring system and the load derivation have been applied using MetOcean data detailed in EX4471 REP101-01-02 EMEC November 2001. The choice of a 10 year and 1 year return period is accepted at face value as a reasonable return period based on the reasoned discussion in CEFOW-WP3-D3.1.1 Mooring Design Report, further interrogation into the application and veracity of environmental data is out of scope. It is noted that the mooring layout is optimised for operation in a directional wave regime from one arc of the compass and particular attention and vigilance should be paid during the operation to forecasts of exceptional wind and waves from other directions. The device has been installed and operational for over a year. We have been provided measured wave information recorded on the site for the first ten months of operation in 2017 (April to December). It is noted that the measured results are substantial and in some cases are close to the predicted 1 and 10 year returns. This demonstrates that the Penguin has survived and operated successfully in extreme conditions substantially as predicted, but also that for a deployment of a longer period than a year consideration should be made to increasing the environmental period return when assessing ULS and ALS cases.

Two worst case examples of the recorded wave environment on site in 2017 and the 1 and 10 year predicted wind/wave environment used by Wello Oy are displayed below, and although the results may not be directly comparable due to limited information available, they do provide an indication of actual conditions experienced against the predicted return periods used in the mooring analysis.

Figure 1Recorded Significant Wave Heights on site April and December 2017

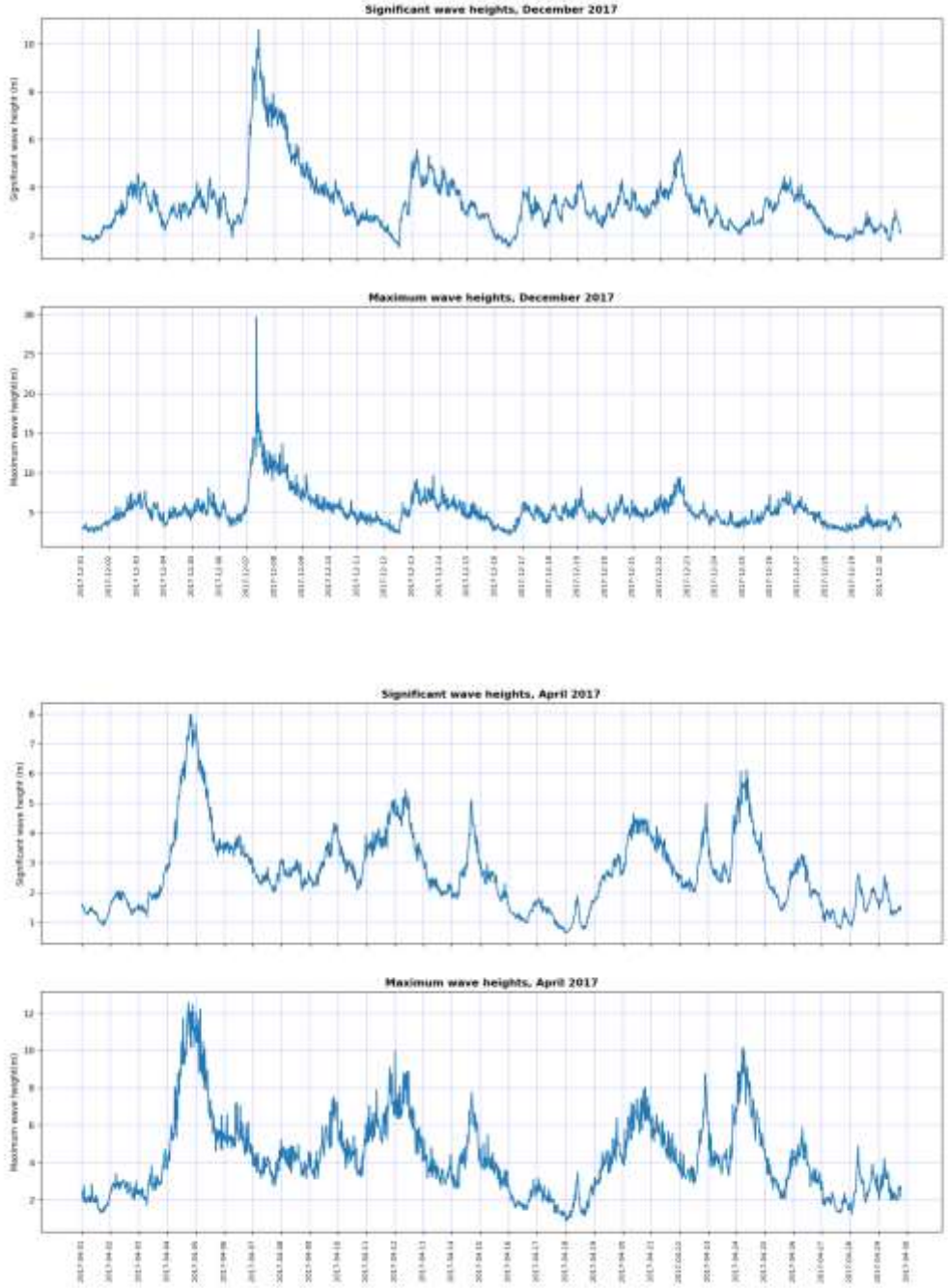


Figure 2 Extract from CEFOW-WP3-D3.1.1-Mooring Design Report ULS Directional Cases - 1 and 10 year return extreme Hs per direction

Compass Direction	Return Period	Hs (m)	Tz (s)	Tp (s)	Wind m/s	Current m/s
210	1	3.8	7.0	9.0	20	0.3
	10	4.6	7.7	9.9	20	0.3
240	1	5.6	8.7	11.2	20	0.3
	10	6.9	9.6	12.3	30	0.3
270	1	8.7	10.9	14.0	40	0.3
	10	10.5	12.0	15.4	40	0.3
300	1	10	11.6	14.9	40	0.4
	10	12.6	13.0	16.7	40	0.4
330	1	8.6	10.7	13.8	40	0.4
	10	11.4	12.3	15.8	40	0.4
360	1	7.5	9.9	12.7	40	0.4
	10	9.7	11.3	14.5	40	0.4

Regulatory compliance

This Third Party Verification Report in conjunction with TPV LGK-C192-P277-E02_rev2 Mooring Due Diligence and accompanying Certificate supported meet the requirement for the application for the Marine Licence subject to approval from EMEC.

Moorings

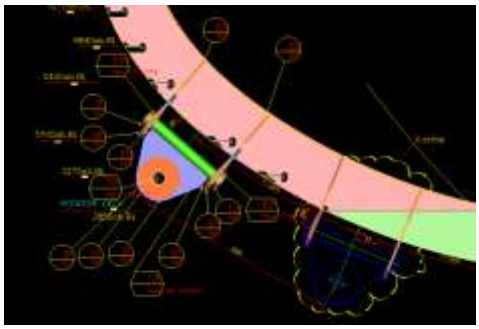
The moorings design has been validated in document TPV LGK-C192-P277-E02_rev2-Mooring Due Diligence, carried out by Longitude Engineering in February 2015. It is assumed that this document relates to the final mooring arrangement as installed. The mooring TPV is accepted at face value and further verification is out of scope. The cable interface with the device is out of scope.

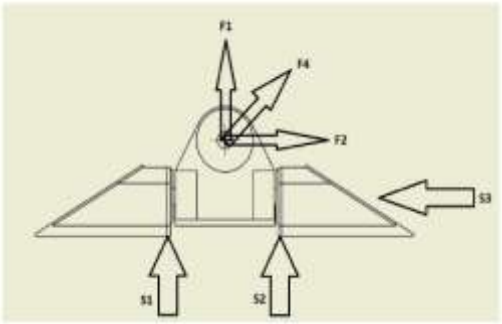
Structural integrity

The focus of this Third Party Verification has been on the mooring attachment points (3 forward anchor brackets and 1 stern anchor bracket) and the retrofitting of ballast boxes on the deck and associated structural modifications.

Based on the information provided it is assumed that the forward anchor brackets and the stern anchor brackets are of the same dimensions [H]. The in-house analysis [B] used 2MN (approx. 204 tonnes) as the maximum load considered and therefore all the anchor brackets are adequate in design. Although there seems to be some minor differences in hull connection design, since the main stress areas identified in [B] are around the pad eye, it is deemed acceptable for the results to be applied for all four mooring brackets. In [G], it was noted that the connection design of the mooring bracket to the hull is different from those along the centerline.

Figure 3 Mooring Bracket Structural Design Differences





To check that the pin can resist the shear stress in this design, for double shear,

$$\tau = \frac{F}{2A}$$

Where, A is the cross-sectional area of the pin,

$$\tau = \frac{2 \times 10\text{^}6}{\pi \cdot (\frac{0.140^2}{4})}$$
$$= 65MPa$$

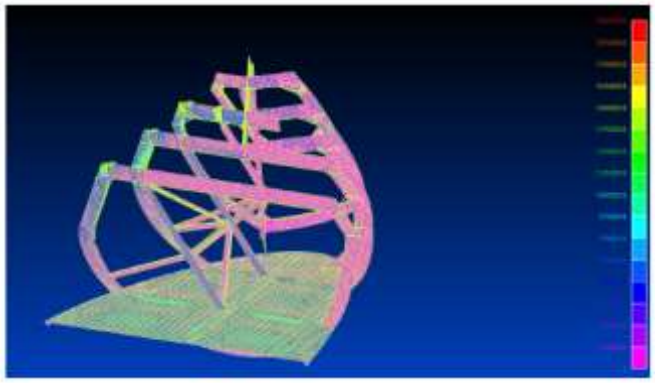
Assuming shear strength as 0.58 of tensile yield strength, shear strength is around 205.9MPa. This gives a safety factor of 3.17 in the pin, and is thus acceptable.

The highest resultant Von Mises stresses as simulated in [D] using FEA was under the loading case with F2, giving 169.3MPa, which indicate that the design is adequate to withstand the loads since there is a safety factor of 2.1 using the material S355.

The mooring brackets therefore fulfill the ULS and ALS check.

It was noted that while the S-N curve referenced in the [J] indicates that the brackets would be able to last 3 years. However, regular inspection during service time should be carried out to ensure that there are not already significant crack propagations in the critical areas. Should signs of such fatigue damage be observed, Non-Destructive Testing may be required to ensure the validity of the component.

The underdeck support structure of the deck ballast was also reviewed. The methodology of the analysis described in [R] to determine the load and the recommended design appears reasonable.



The analysis suggests that the proposed design does not have high stress concentration on the support structure. It was however noted that the [R] concluded that analysis on the detailed design of the support structure was not completed. Between this work and the finalizing of the detailed design in [R] & [T], it was assumed that proper analysis was carried out. However, subjected to inspection of the existing structures for any buckling, deflections, cracks or other damages, the deployment history suggests that the structure should be fit for further deployment.

Installation and operations

The device is already installed and has been operating for over a year. Four ROV inspections have been undertaken and two reports (including the last) have been reviewed. It is noted that at the last inspection the mooring attachment points were covered in weed growth.

Conclusion

We conclude that, subject to the limitations of this TPV and the conditions set out in this document, the Penguin wave energy device structure and moorings connections are verified as being appropriate for a monitored 12 month deployment at the EMEC Billia Croo Berth 1 location.

3 Reference Documents, Codes and Guidelines

Table 1 Reference Document Codes and Guidelines

S/N	Document	Rev.	Use in this report
1	DNV-OS-E301 Position Mooring	2015	Environmental Conditions and Mooring Loads
2	IEC TS 62600-10:2015 Assessment of Mooring System for MECs	2015	Environmental Conditions and Mooring Loads
3	DNVGL-OS-C101 Design of offshore steel structures, general	2017	Review of structural analysis of the underdeck support structure for ballast box
4	DNV OS-C201 Structural Design of Offshore Units	2014	Review of structural analysis of the underdeck support structure for ballast box
5	DNVGL-RP-C203 Fatigue design of offshore steel structures	2016	Review of structural analysis of the mooring brackets
6	HSE MCA Regulatory Expectations	2017	Guidance

4 Submitted Documents

The documents shown in Figure Table 2 have been submitted by Wello Oy and have been used during this verification process.

The status of the submitted documentation is labelled accordingly:

DOC - Primary documents reviewed with comments, conditions, and assumptions
INF - Taken for information and / or providing input for execution of scope

Table 2 Submitted Documentation

S/N	Document	Rev.	Status
A	CEFOW-WP3-D3.1.1-Mooring Design Report	Rev 1.0, 2016	DOC
B	Mooring bracket strength analysis	2011	DOC
C	Checking of bracket's strength	-	INV
D	Mooring bracket strength analysis	2011	DOC
E	AN 012-04-01_6	2011	INF
F	AN-012-00-10	2011	INF
G	AN0121101 NEW BR REVA[4] (1)	2013	INF
H	Certificate no. GLS 1102559	2011	INF
I	TPV LGK-C192-P277-E02_rev2 Mooring DD	2015	DOC
J	WD-5002-TN	2017	DOC
K	PW500101057100B	2011	INF
L	PW500101057201	2011	INF
M	PW500101057100	2011	INF
N	PW500101057200B	2011	INF
O	PW500101057202	2011	INF
P	PW500101057200	2011	INF
Q	DRR No. EP019815-01 Rev0	-	INF
R	LGK-001052-CN01	2015	DOC
S	Wello penguin - forward box INT structure fab drawings	2016	INF
T	Wello penguin - stern box INT structure fab drawings	2016	INF
U	ROV Inspection report	06.07.2017	DOC
V	ROV Inspection report	05.01.2018	DOC
W	Technical Note CEFOW-WELLO-INSP01	2017	INF

5 Conditions Limitations and Assumptions

5.1.1 Environmental limits, weather forecasting and on site measurements

Additional vigilance should be applied in when extreme conditions are forecast from directions other than that used in determining maximum ULS and ALS cases.

5.1.2 Routine device monitoring

It is noted that the Penguin has survived and operated successfully in extreme conditions for a period of over a year. Two ROV inspections have taken place during this period, (6th July 2017 and 5th January 2018). The latter inspection, in particular, has limited value due to the extent of marine growth over the mooring attachments. It is understood that the main mooring components will be pressure washed and visually inspected by divers in May 2018. Where practicable, it is strongly recommended that at this time underwater (NDT) crack detection methods should be used on the welds and structure of the mooring brackets to ensure that they are sound. The visual inspection should also focus on detection of indications of wear and deformation on bracket pins and connecting shackles.

5.2 Summary of Conditions

1. The next inspection plan based on CEFOW-WELLO-INSP01-021017 to be agreed by Orcades Marine and should include NDT crack detection where practicable
2. The results of the next inspection to be informed to Orcades Marine
3. The condition of the device is assumed to have remained substantially unchanged since deployment. Any change detected in the condition of the device structure or its moorings and restoring and/or mitigating actions should be advised to Orcades Marine and may result in a requirement for further TPV.

6 Communications Log

6.1.1 Summary of Document and Information Exchange

Date	Action	Document
29th April '18	TPV Completed	OP212.01 and OP212.02
27th April '18	Recorded wave information for site received	Email
25th April '18	Clarification on brackets requested and received	Email
20th April '18	ROV images uploaded to dropbox	Email
20th April '18	ROV Inspection reports received	Reports x 2
20th April '18	Information of attachment points requested	Email
16th April '18	Shared Dropbox set up for documentation exchange	Email
16th April '18	Clarification on scope received	Email
12th April '18	Instructions to proceed	TPV LGK-C192-P277-E02_rev2

7 Applicability

Specialist knowledge and practical experience has been applied to the process of Third Party Verification by Orcades Marine, and whilst reasonable care and diligence has been taken during the Third Party Verification process, part of the process may be based on information that has been provided by the Client, where this can be justifiably relied upon. The Third Party Verification of the project is limited to the overall scope of work agreed with the Client. Therefore the validity of the Third Party Verification is only applicable to circumstances that are reasonably and practicably foreseeable.

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