Document Title

TECHNICAL OVERVIEW

Mooring System Design

Document Classification

EXTERNAL

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Revision History

Rev.	Date	Description	Prep	Chk	App
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R04	08/04/2018	Issue for Review	RR	AW	RR

Changes since Last Revision

Rev.	Date	Purpose	List of updated sections/pages
R02	25/03/2018	Update Following TPV	Changes as described in Appendix L
R03	04/04/2018	Update Following TPV	Small changes as described in Appendix M in particular more detail in Section 14.4 regarding a proposed hull appurtenance to reduce the moment at the hull attachment point.
R04	08/04/2018	Update Following TPV	Appendix

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1. INTRODUCTION

1.1 PROJECT OVERVIEW

The Magallanes Tidal Energy Converter (TEC) is an offshore floating tidal energy platform, named ATIR, which will be deployed at the EMEC tidal testing site in the Fall of Warness (FoW), Scotland at Berth 1, in a water depth of 49 meters (LAT). The Magallanes platform will be carrying two tidal turbines with a combined rated power output of 1.7MW.

Figure 1-1 – Deployment location at Eday (Orkney Isles)

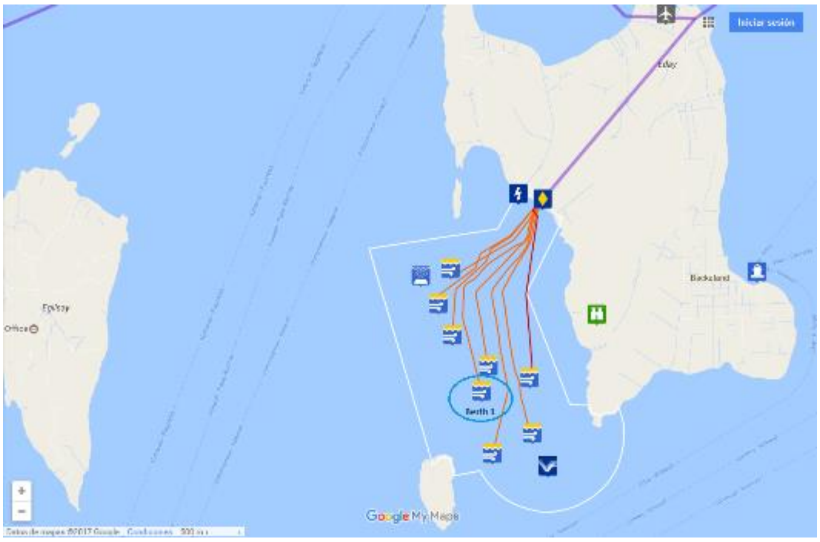

Figure 1-2 – Deployment location at Eday (Orkney Isles)

The device has been built in Spain and will be towed to Shapansay Sound (East of Kirkwall) for commissioning. The device will then be installed onto its preinstalled mooring system in the Fall of Warness. It will be in place for a period of at least 12 months for testing and validation. The mooring system consists of four lines and four gravity anchors.

The mooring system has been designed for 10-year survival conditions. The analysis is based on DNV-OS-E301[1].

The hull shape is optimised to minimise yaw and pitch, to maximize tidal energy capture. The hull freeboard is minimised to reduce wind loading but sufficient to ensure its stability.

Prior to commencement of the work it is required to satisfy a TPV that:

- Mooring components and structural attachments are sufficient for the duration of the work and the probability of capacity being exceeded is acceptable;
- The mooring equipment has no / extremely low risk of contact with other subsea assets;
- Operational measures are in place to reduce failure probability and to mitigate failure events.
- The risk to EMEC infrastructure is none / negligible.

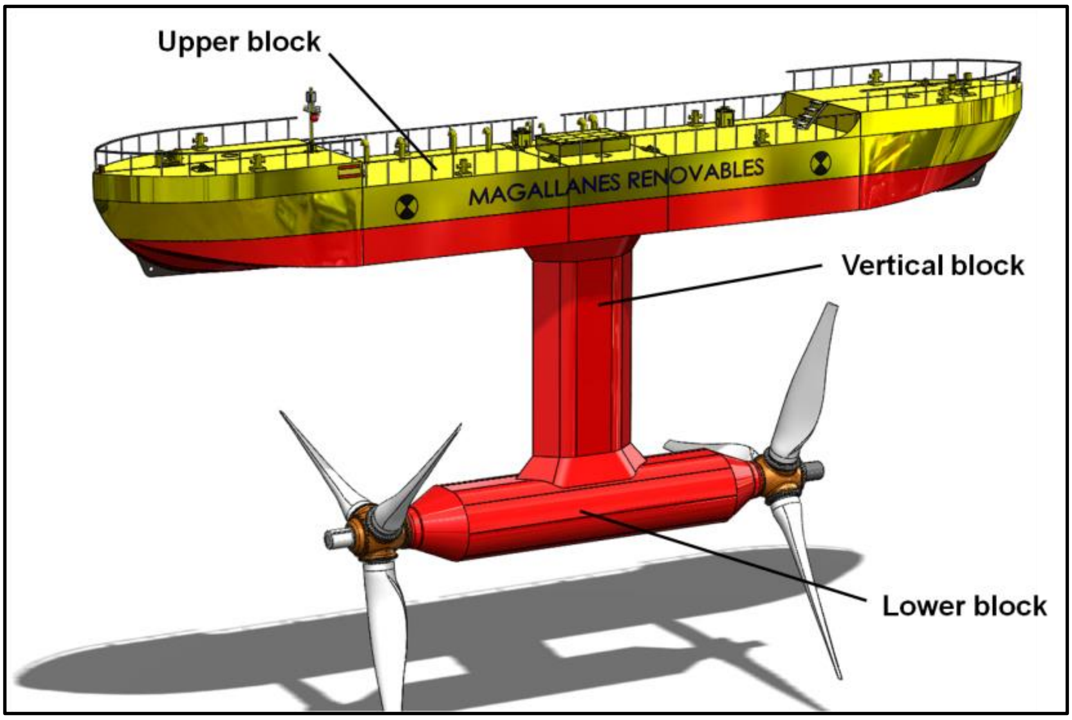

Figure 1-3 –Magallanes – Offshore Floating Tidal Energy Platform

1.2 DOCUMENT OBJECTIVE

This report outlines the design methodology and clarifies any assumptions used for the mooring analysis, to show that the mooring is fit for purpose.

- Mooring Component Capacity and Mooring Attachment points have been assessed in accordance with DNVGL-OS-E301 Ref [1] and.
- Anchor capacity and anchor sizing anchor is based on loads derived within 3-hour simulations as recommended by DNVGL-OS-E301, but moderated with engineering, operational monitoring and statistically based arguments

This report is submitted in fulfilment of the requirements of Magallanes Renovables S.L. for the mooring system design of a floating tidal energy converter, which will be installed in the Fall of Warness.

The report is created both for internal project engineering, and for submission to a third-party, for review and approval, as per conditions of the berth agreement at EMEC.

The report presents the input data, a description of the methods used for the determination of design load cases, and the assessment of the Ultimate Limit State and Failure Limit State, as specified in Ref [1].

1.3 CHANGES SINCE R01

1.3.1 STRUCTURAL

This report has been updated following TPV comments and also to react to a structural assessment document by the TPV (Reference 20) with some onerous conclusions.

The objective of the TPV structural analysis was sound in assessing load as a function of angle. It was a deficiency of the R01 mooring design report not to specify angle tension plots. However, this TPV work had to rely on assumptions and back calculating and there were also some errors and assumptions making it a conservative assessment[1].

[1] - Maths error resulting in higher angle of the mooring line to the centre line (50.7 degrees versus 32.3degrees). This will have a significant effect on results.

- Incorrect assumption that mooring loads are all acting at the same time. IN Section 6.3 of the report it is pretty clear that the analysis derives the maximum load at each connection point in the 3 hours and these loads are no coincident but the maxima in each component.
- Incorrect assumption that vessel does not yaw at the same time as load and therefore angle of load is a function of all the variables (vessel motion, environment, load) at each time step and not the static position
- Central bulkhead does not seem to have stiffeners in the TPV structural assessment model which must be a cause for the significant buckling
- Does the Plate connecting the shackle connection point stop at the underside of the hull or go inside as it should? The model is not clear.

In order to address these structural concerns

- More effort was placed on assessing the actual load vectors and their influence on the structure and this work is presented in Section 14.
- A 3D model from the designers Seamasters was sued to create an FEA model.
- Extreme loads at various angles (250t at 0, 15 and 30 degrees relative to centre-line, 175t at 0, 15, 30).
- Further mooring analysis was then performed to create angle tension plots for structural assessment of key loads cases (example below)
- FEA was then re-run with these angle tension plots.

1.3.2 MOORING ANALYSIS

The mooring design has also been updated. As well as addressing some points raised by the TPV to R01.

- An error was found in the mooring analysis file which resulted in the MOSES origin being incorrectly used in the Orcaflex file. This resulted in too high yaw at Northerly headings and too low at Southerly. This error has reduced Northerly loads quite significantly and increased Southerly slightly.
- The system has been optimised to take some aspects used in the Pelamis mooring system where the two legs are joined together just above the seabed. This helps to spread load more between the lines but will operationally challenging.
- To aid operational hook-up and also planned and emergency disconnection, a small element with reduced stiffness characteristics was added. This is a 35m length of synthetic (Bridon Superline Polyester) above the ground chain.

1.4 PROCUREMENT / FINAL DESIGN

This is a research and development project which does not benefit from industrial levels of budget and resource.

Therefore, the design solution presented here considers project budget and a reasonable level of technical risk (for example reduced SF for chain clumps, slight local yielding in ULS oblique sea cases). This technical risk is considered acceptable because the R&D nature of the project means the device will be subject to extensive monitoring.

The design presented here may be modified slightly prior to installation based on the supply chain achieving costs which meet the project budget.

A TPV is therefore sought based on some flexibility to account for:

- **Available procurement** – chain for clumps varies in price and it may be more economic to use second hand solid steel clump weights
- **Operational optimisation** – hooking up the end clumps and in-line clumps may guide different sizes and quantities (not affecting the total capacity)
- **Design Optimisation** – further structural assessment and potential optimisation

2. EXECUTIVE SUMMARY

2.1 SUMMARY OF WORK

Using engineering data provided by Magallanes of the tidal platform and the environment:

- A hydrodynamic model of the tidal platform has been developed in MOSES and transferred to Orcaflex.
- An Orcaflex model has been developed using current, wind and blade coefficients developed from code, engineering documents and empirical data.
- Various mooring concepts have been developed towards the optimised solution and these are presented.
- An umbilical configuration has been designed using a lazy S configuration where the umbilical is maintained at a specified depth with both buoyancy and a clump weight. Although outside the scope of this report, the work is summarised.

2.2 MOORING SYSTEM OVERVIEW

The mooring system consists of 4 chain catenary legs, two north and two south, attached to one hull attachment points at the bow and stern.

The mooring system holds the ATIR platform in line with the current flow. The final design is shown in Figure 2-1.

- Two legs are positioned along the centre-line, principally in line with the flow (approximately 10degrees off).
- Two legs are offset from the centre-line by 45 degrees to the west. These lines assist in reducing device yaw and easterly excursion.
- The anchor weights are not identical and are specified accordingly to the lines which experience the greatest ULS loads. In summary: NW - 90 Te, NE - 161 Te, SE - 163 Te, SW - 137 Te

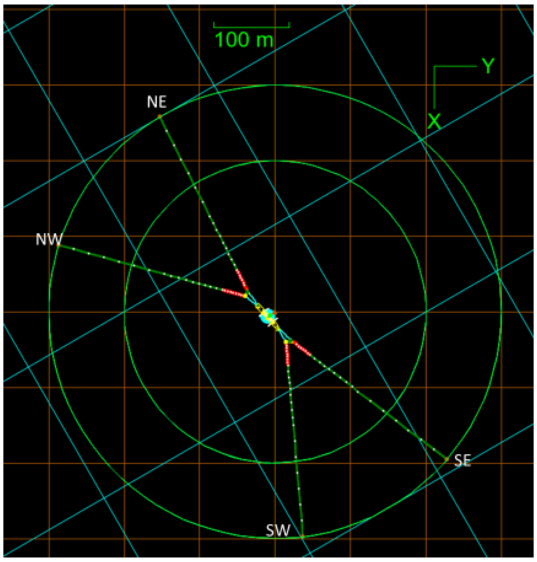

Figure 2-1 - Proposed Mooring System

2.3 MOORING COMPONENT SUMMARY

Each mooring leg is identical, but only up to the gravity anchors themselves. The anchor sizes vary due to the statistically derived environmental loading and the larger environmental forces from the North:

- **Hull Attachment**
  - A single padeye at the bow and stern, in which a single shackle is connected.

- **Upper Catenary**
  - 5m of 76mm chain
  - 40m of 80mm Bridon Superline Polyester
  - 5m of 76mm chain

- **Excursion Limiter**
  - 30m of 111mm chain or similar arranged in 4 lengths of 30m

- **Ground Chain/Lower Catenary**
  - 225m of 76mm chain

- **Anchor**
  - The device is connected to the seabed using four Chain Clump Weights with a total capacity (wet weight) as follows:
    - NW – 90 Te
    - NE – 161 Te
    - SE – 163 Te
    - SW – 137 Te
  - The wet weight capacity is defined by the ULS loads not the ALS loads.
  - Instead of defining the capacity according to the higher ALS loads, it is proposed to link the in-line or end chain clumps such that both anchors may assist in an ALS scenario.
  - End Weight Clumps Anchor (dry-weights)
    - Final weights to be confirmed following design & operational optimisations
      - NW – 75-150Te Chain Clump
      - NE – 75-150Te Chain Clump
      - SE – 75-150Te Chain Clump
      - SW – 75-150Te Chain Clump
  - In Line Clump Weights (dry-weights)
    - Final weights to be confirmed following design & operational optimisations
      - NW – 75-150Te Chain Clump
      - NE – 75-150Te Chain Clump
      - SE – 75-150Te Chain Clump
      - SW – 75-150Te Chain Clump

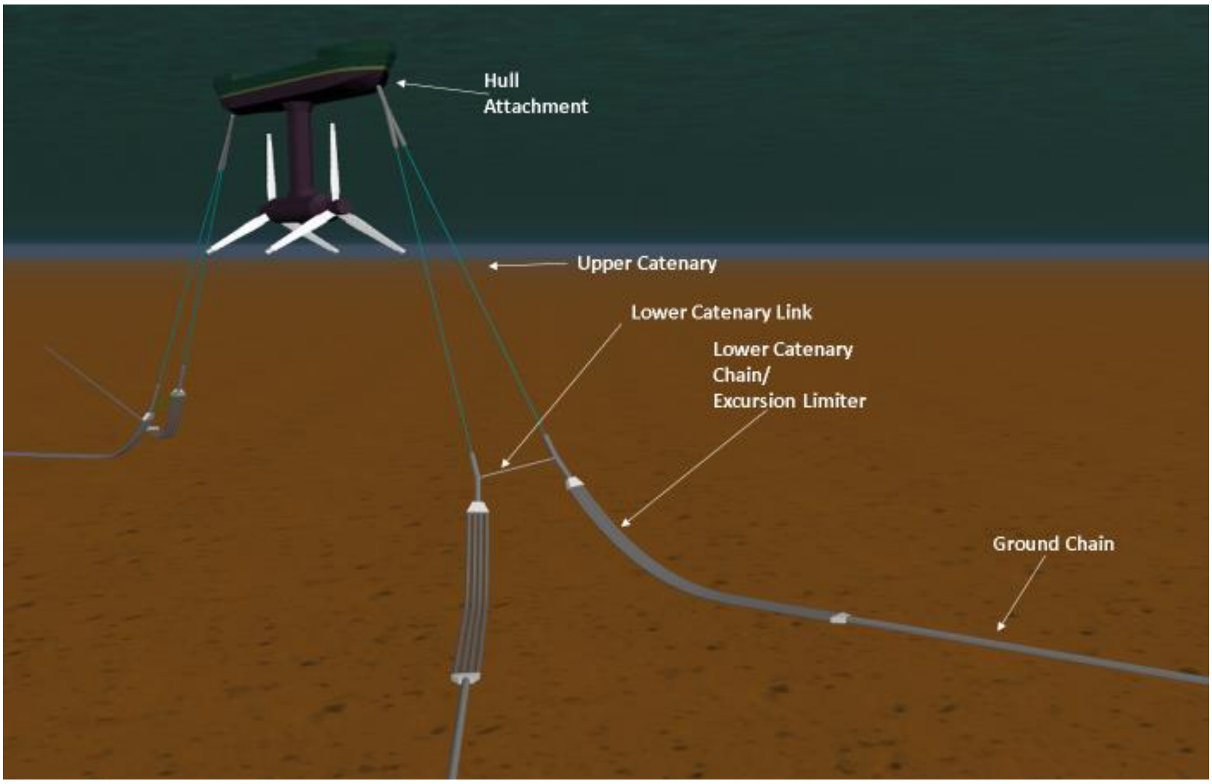

Figure 2-2 – System Breakdown of Magallanes mooring system

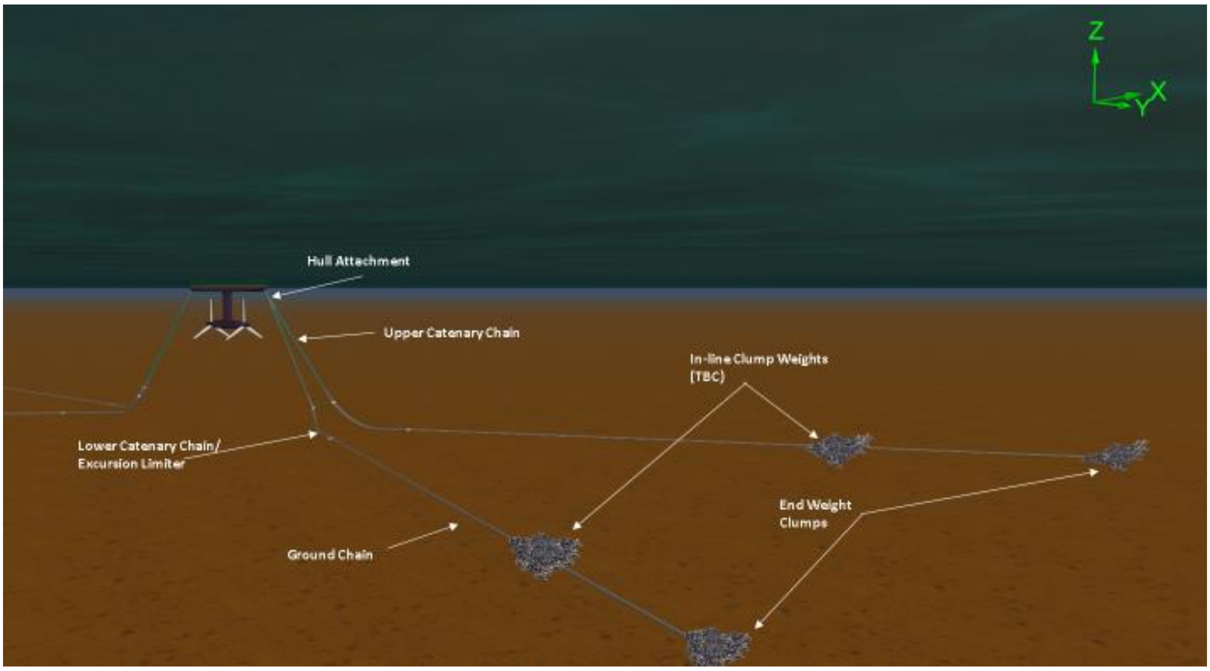

Figure 2-3 – High Level Overview of system with gravity chain clumps

2.4 SUMMARY OF LOADS & UTILISATIONS

2.4.1 LOAD SUMMARY

A summary of factored ULS, Operational and ALS loads is presented in Table 2-1.

								Factored Loads									
								Tension at Hull (Te)					Tension at Anchor (Te)				
Type	LC	Wave Direction		Current	Vc (m/s)	Hs(m)	N_Hull	NW	NE	S_Hull	SE	SW	NW	NE	SE	SW
Survival	13	150	SSE	Wind & Waves AGAINST	3.5	5.6	109	71	84	232	124	112	72	81	131	109
	19	180	S	Wind & Waves WITH Tide	1.5	3.1	102	50	84	134	89	60	50	82	91	56
	37	210	SSW	Wind & Waves SLACK W	0.0	2.7	108	70	80	131	95	46	63	78	89	49
	49	240	WSW	Wind & Waves WITH Tide	1.5	2.6	110	68	88	109	78	33	58	91	78	37
	61	270	W	Wind & Waves AGAINST	1.5	2.7	106	63	83	103	74	32	56	86	75	38
	76	300	WNW	Wind & Waves AGAINST	1.5	3.4	112	70	87	106	75	32	62	89	76	37
	96	330	NWN	Wind & Waves SLACK W	0.0	4.7	193	67	135	114	79	36	58	129	80	40
Opp	106	150	SSE	Wind & Waves WITH Tide	3.5	1.8	16	10	8	158	78	82	13	10	80	85
	113	180	S	Wind & Waves WITH Tide	3.6	1.8	23	15	10	156	82	80	17	10	84	83
	120	210	SSW	Wind & Waves WITH Tide	3.6	1.8	29	21	11	154	79	78	21	10	82	83
	126	240	WSW	Wind & Waves WITH Tide	3.6	1.8	28	20	12	142	77	69	20	10	79	74
	134	270	W	Wind & Waves WITH Tide	3.5	1.8	152	53	101	16	9	8	50	107	13	10
	140	300	WNW	Wind & Waves WITH Tide	3.5	1.8	153	53	100	15	8	7	50	105	12	10
	148	330	NWN	Wind & Waves WITH Tide	3.5	1.8	161	61	100	13	5	9	60	103	11	11
ALS	ALS_1	150	SSE	Wind & Waves WITH Tide	3.6	3.0	173	149	24	199		199	149	7		205
	ALS_2	150	SSE	Wind & Waves WITH Tide	3.6	3.0	124	97	39	0			101	28		
	ALS_3	240	WSW	Wind & Waves WITH Tide	3.6	1.6	119	103	16	161		161	96	7		167
	ALS_4	240	WSW	Wind & Waves WITH Tide	3.6	1.6	77	55	29	0			58	16		
	ALS_5	270	W	Wind & Waves WITH Tide	3.5	2.5	126		126	91	76	15		128	65	8
	ALS_6	270	W	Wind & Waves WITH Tide	3.5	2.5	0			84	73	33			72	23
	ALS_7	330	NWN	Wind & Waves WITH Tide	3.5	2.1	131	131		93	17	77	132		8	64
	ALS_8	330	NWN	Wind & Waves WITH Tide	3.5	2.1	0			84	72	38			70	30

Table 2-1 - Summary of Loads

2.5 ANCHOR CAPACITY

The gravity anchors have not been specified by the project strictly according to DNV-OS-E301. Instead of factored capacity a safety factor of 1 has been used. This is justified by:

- Total redundancy - linking of in-line or end clump weights instead of sizing anchors for the maximum ALS cases.
- A close monitoring regime of both device excursion using GPS linked to the control system, and design loads monitored by load shackles;
- The potential to modify the system post installation. This will be achieved, either by adding a pair of chain clumps either side of the ground chain prior to the anchor or adding a chain clump to a tail left from the anchor after installation;
- The 0.8 friction coefficient is conservative considering drag trials on site;
- The lack of necessity to achieve DNV class approval of the system;
- Maintaining no/negligible risk to both the project and third-party assets;
- Proving the economic case for a potential industry;

Anchor sizing is also supported by recognising that peaks in anchor tensions are momentary spikes of a few seconds.

A statistical assessment of a 3-hour simulation:

- **Total Duration Over 3 Hrs** – total period during the 3 hours storm when the anchor loads exceeded the maximum anchor utilisation limit
- **No. events** - The number of events
- **Max. Duration One Event** – The duration of event.

Table 2-2 summaries the statistical results highlighting how peak tensions occurred during a few seconds within a 3-hour 10-year storm. Such brief peak loading affects anchor position by a negligible distance and therefore of no consequence to mooring loads within the components which are sized strictly according to DNV-OS-E301, the dynamic cable or third-party assets. Hence it is comfortable that the anchor capacities are suitable.

Event	Max. Duration One Event (s)	No. Event	Total Duration Over 3 Hrs (s)
Peak 1	4.8	23	38
Peak 2	1.9	1	2
Peak 3	4.1	2	6
Peak 4	1.2	1	1
Peak 5	0.5	2	1

Table 2-2 - Time History of Loads in NW line

2.6 MOORING POSITIONS

The preferred and proposed position of the mooring system (subject to EMEC approval) is as per Figure 2-4 and Table 2-3. This position is closer to the original berth position prior to an altered proposal by EMEC in October 2017. The reason for the preference is as follows:

- This configuration retains no risk to nearby berths in the worst single failure (loss of southerly mooring attachment).
- Intact proximity to the Scotrenewables device is 526m. The minimum "academic" damaged proximity is 300m. It is academic because the seabed has friction and the direction of the force vector is difficult to be to the NE for any duration.
- The EMEC proposal resulted in the SE mooring leg crossing the EMEC Berth 3 cable.
- The South-East mooring line is clear of the EMEC Cable of Berth 3 by 25m.
- The resulting dynamic cable length of around 150m improves project costs.

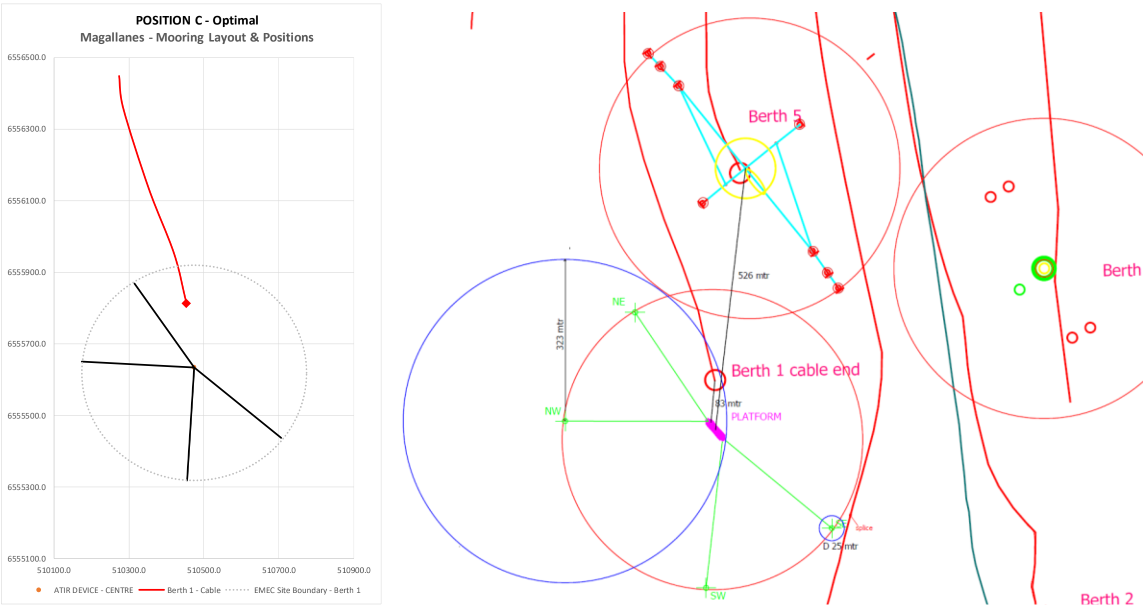

Figure 2-4 – Left – Simple Schematic of preferred Mooring Position B. Right – Detailed Schematic encompassing other berths - Blue circle indicates maximum academic excursion following worst single failure of southern hull connection)

	Northing	Easting
Device	510475	6555634
NE Anchor	510314	6555868
NW Anchor	510175	6555651
SE Anchor	510707	6555437
SW Anchor	510456	6555318

Table 2-3 – Position A - Mooring Positions as Proposed by EMEC

3. REFERENCES

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2. Environmental Conditions and Environmental Loads DNV-RP-C205
3. Design of Floating Wind Turbine Structures, DNV-OS-J103
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20. MAGALLANES TPV - STRUCTURAL - Rev 3 – Orcades Marine

4. NOMENCLATURE

ANACRONYM	DESCRIPTION
ALS	Accidental Limit State
AWL	Waterplane area (m2)
DLC	Design Load Case
ESS	Extreme Sea State
FLS	Fatigue Limit State
FoW	Falls of Warness
GML	Longitudinal Metacentric Height (m)
GMT	Transverse Metacentric Height (m)
HAT	Highest Astronomical Tide
Ixx	Inertia about reference X axis (m)
Iyy	Inertia about reference Y axis (m)
Izz	Inertia about reference Z axis (m)
JONSWAP	Spectrum from Joint North Sea Wave Project
Kxx	Radius of gyration about reference X axis (m)
Kyy	Radius of gyration about reference Y axis (m)
Kzz	Radius of gyration about reference Z axis (m)
LAT	Lowest Astronomical Tide
LCF	Longitudinal centre of flotation (m)
LCG	Longitudinal Centre of Gravity about defined vessel origin (m)
MSL	Mean Sea Level
NSS	Normal Sea State
SLS	Serviceability Limit State

SSS	Severe Sea State
TCG	Transverse Centre of Gravity about defined vessel origin (m)
ULS	Ultimate Limit State
VCG	Vertical Centre of Gravity about defined vessel origin (m)
XCG	Centre of Gravity about reference X axis (m)
YCG	Centre of Gravity about reference Y axis (m)
ZCG	Centre of Gravity about reference Z axis (m)

5. BACKGROUND

5.1 LOCATION

The Magallanes Tidal Energy Converter (TEC) is an offshore floating tidal energy platform, named ATIR, which will be deployed at the EMEC tidal testing site in the Fall of Warness (FoW), Scotland at Berth 1 at 59° 08.479’ North, 002° 49.080’ West WGS84, in a water depth of 49 meters (LAT), see Figure 5-1.

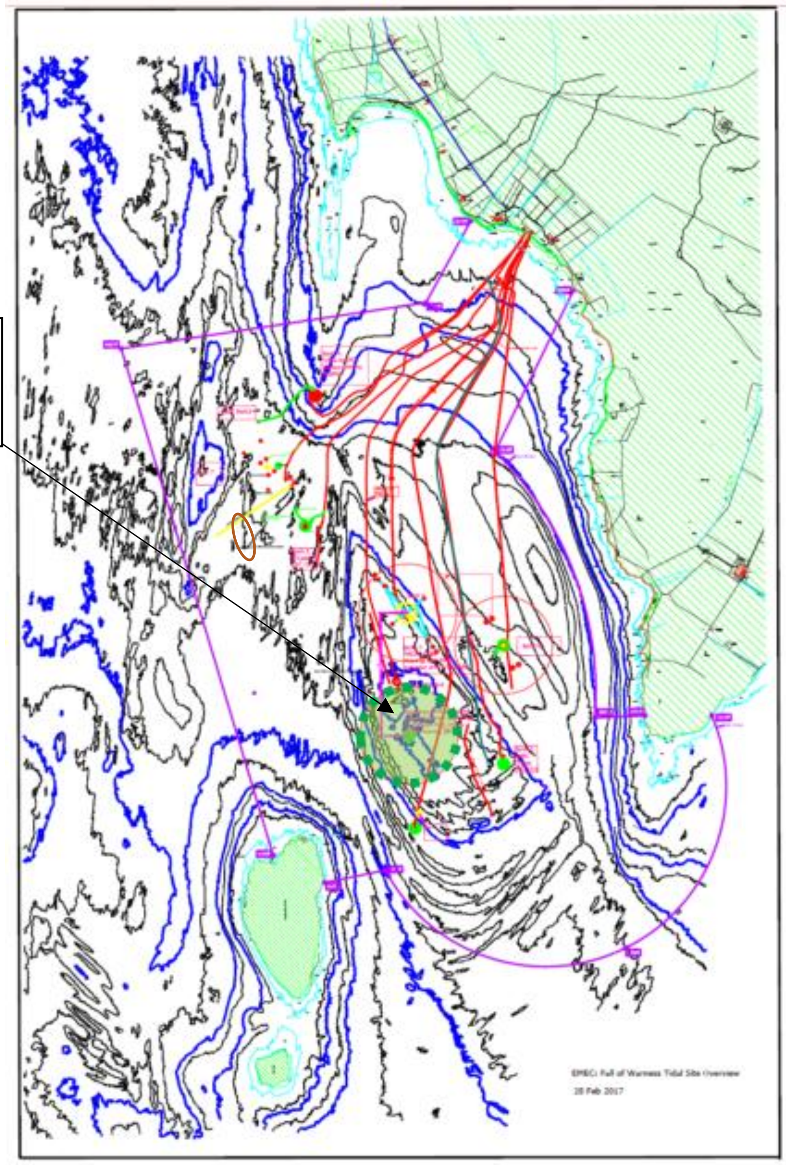


Figure 5-1 - Overview of Fall of Warness, the green highlighted areas showing the location proposed by EMEC for Berth 1

5.2 PROJECT DESCRIPTION

Following successful scale testing (1:10) in various locations in Spain (including Redondela, Vigo estuary, estuary of Miño River) in 2012, and at EMEC in 2015. A full-scale design began in 2013 with the finally assembly in 2015, the company set about upgrading the Magallanes platform and device launch took place in Vigo, Figure 5-2. The blades are installed in deeper sheltered waters with divers, due to port quayside draft constraints. The device will be carrying two tidal turbines with a combined rated power output of 1.7MW.

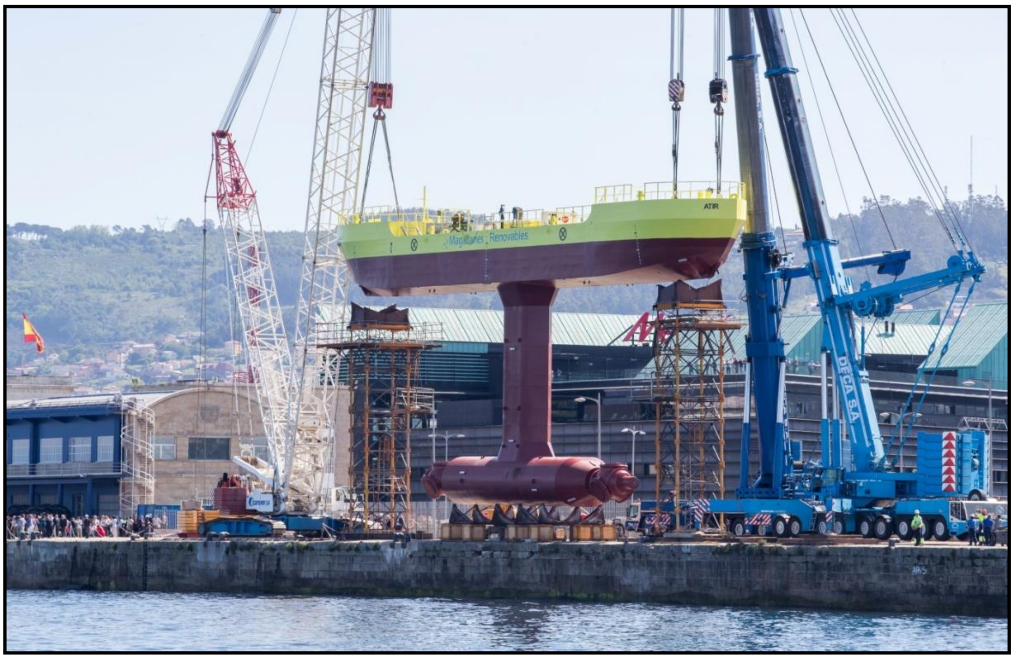


Figure 5-2 – Device Launch in Vigo (Spain)

Following open water tests the device will be installed at EMEC's full scale tidal test site at the Falls of Warness. It is intended to be installed for a minimum of 12months:

- To demonstrate the operational performance of a grid connected full-scale prototype in a real open sea environment;
- To improve the prototype for cost competitive energy generation;
- To pre-certify the real-scale prototype, with an independent electrical power performance assessment;
- To develop a business strategy and marketing approach according to the project outputs and to identify potential customers during the project deployment.

The information obtained from tests will be crucial for the future of the project, since it will help to confirm whether the costs of installation, operation, maintenance and removal, together with the electricity generated, fit with what had been forecasted.

6. ANALYSIS METHODOLOGY

6.1 SUMMARY

An Orcaflex model was created using current coefficients developed using various methods described in Section 7, and wave load properties developed within MOSES.

Dynamic simulations in this detailed design report stage over a 3hour simulation were run in Orcaflex for a range of environmental conditions for both an intact and damaged mooring system (where the damaged system was the result of the worst single failure).

Results are reported for:

- Excursion,
- Mooring Connection Point Tension,
- Riser Tension,
- Ground Chain Tension,
- Anchor Lateral and GZ Force.

6.2 SOFTWARE

The mooring analysis is performed using Orcaflex dynamic simulation software (www.orcina.com). Orcaflex is a fully 3D non-linear time domain finite element program; the software provides fast and accurate analysis of a wide range of offshore systems under wave loads and externally imposed motions.

Three-dimensional diffraction analysis for the development of wave load coefficients was carried out using MOSES (http://bentley.ultramarine.com/). MOSES is a general-purpose program for analysis of general fixed and floating offshore structures, which is widely used in offshore design and installation engineering.

6.3 ANALYSIS PROCESS

Orcaflex and MOSES was used for the analysis, with the following steps followed:

1. Environmental criteria established (wind, current, Hs, Tp, Duration, Spectra);
2. Determine initial mooring pattern;
3. Determine hydrodynamic properties, current and wind force coefficients of body and mooring system;
4. Perform time domain simulations for each seastate for 3hours.
5. Record the maximum deterministic value from the three simulations.
6. Determine, using appropriate factors (as described in Section 6.5) the design load.
7. Verify component MBLs are sufficient, and optimise if required;
8. Re-run following system optimisations.

6.4 LIMIT STATE SIMULATIONS

DNV-OS-E301 asserts that the mooring system shall be assessed according to design criteria formulated in terms of various limit states:

1. **ULTIMATE LIMIT STATE (ULS)** - to ensure that individual mooring lines have adequate strength to withstand the loads resulting from extreme environmental actions.

2. **SERVICE LIMIT STATE (SLS)** - to ensure components have adequate capacity in the operational condition.

3. **ACCIDENTAL LIMIT STATE (ALS)** - to ensure components have adequate capacity in the worst single failure.

4. **FATIGUE LIMIT STATE (FLS)** - to ensure components have adequate capacity to withstand cyclic loading.

In this analysis the ULS, SLS and ALS cases were assessed.

The FLS was not assessed due to the short duration of the mooring testing programme.

6.5 ULTIMATE LIMIT STATE

The ULS load cases are split into various areas, intended to capture the extreme response and loads the mooring system will encounter at the site instead of merely an applying the maximum Hs and associated Tp. The sections cover;

- **ULS – DIRECTIONAL** - The effect of directionality by applying extreme return waves at various headings.
- **ULS – FORM** - The effect of system resonance by applying extreme wave heights across the range of likely wave periods (Tp of 3.5 – 16.8 second), as required in Ref.1 Section 2.2.1. A method was derived as described in Section 10, which is as close as feasible with the extent of data provided to the FORM approach.
- **ULS – CURRENT** - The effect of extreme wind and current conditions with representative secondary Metocean parameters.
- **ULS – WIND** - The effect of extreme wind will be applied colinearly with all wave cases.

The ULS checks must confirm that all components of the mooring system have sufficient reserve capacity/do not exceed specified utilisation levels. This was achieved by selecting extreme load cases, assessing the mooring tensions and applying appropriate safety factors, to determine the required strength of components in the system.

The governing equation for the assessment of the Ultimate Limit State is shown below (Chp2, Section 2, Para 4.2.1, Reference 2);

$$u = \frac{T_{c-mean}\gamma_{mean} + T_{c-dyn}\gamma_{dyn}}{S_c} \ where\ u \leq 1$$

Where;

- u – Utilisation factor which must be equal or less than 1
- $T_{c-mean}\gamma_{mean}$– The characteristic mean line tension, due to pretension and mean environmental loads. The mean environmental loads are caused by static wind, current and mean wave drift forces.
- T_{c-dyn}– The characteristic dynamic line tension induced by low-frequency and wave-frequency motions.
- T_{mpm}– Most probable maximum from the time series

$$T_{c-dyn=} T_{det} - T_{c-mpm}$$

- S_c – Characteristic breaking strength of component
- S_{mbs}– Mean breaking strength (as specified by manufacturer or through tests).

$$S_c = 0.95 S_{mbs}$$

- γ_{mean}– Partial safety factor on mean tension
- γ_{dyn} – Partial safety factor on dynamic tension

6.5.1 ULS – PARTIAL SAFETY FACTORS FOR LINE COMPONENTS

The partial safety factors to be applied depend on the Consequence Class of the Installation. The Atir tidal platform Installation has been classed as Consequence Class 2, as per DNV-OS-E301, Section 4.1.1:

- **Class 1 -** where mooring system failure is unlikely to lead to unacceptable consequences such as loss of life, collision with an adjacent platform, uncontrolled outflow of oil or gas, capsize or sinking.
- **Class 2 -** where mooring system failure may well lead to unacceptable consequences of these types.

Consequence Class	Type of Analysis	Partial Safety Factor on mean tension γ_{mean}	Partial Safety Factor on dynamic tension γ_{dyn}
1	Dynamic	**1.10**	**1.50**
2	Dynamic	1.40	2.10
1	Quasi-Static	1.70	
2	Quasi-Static	2.50	

Table 6-1 – ULS Partial Safety Factors as per Reference 2, the bold values denoting the factors used in this analysis.

6.5.2 ULS – PARTIAL SAFETY FACTORS FOR GRAVITY ANCHORS

A deviation in the safety factors from DNV-OS-E301 is proposed for the gravity anchors based on the following five considerations:

1. The consequence of failure /insufficient safety factor
2. The time history of loads assuming a constant environment over three hours
3. The reality of the actual feasible time history of loads on the site
4. The monitoring regime on the platform / model correlation / anchor adjustment
5. The friction coefficient of 0.80 proposed

Consideration 1: The consequence of failure /insufficient safety factor

- For chain and links, the consequence of failure is very significant. Therefore, simulations are run with a constant environmental force for three hours, as per DNV-OS-E301, to attain the highest load which is then factored as per DNV-OS-E301. This is desirable and appropriate, due to material variations, corrosion, degradation in service, etc) and because of consequence.
- For gravity anchors, the consequence of over utilisation (above the gravity anchor sizes proposed) is trivial. This is because the actual duration these over-utilised factored loads occur is not of sufficient duration to move the gravity clumps more than 1-2m, as presented in Section 13.

Consideration 2: Time history of loads

- The actual duration factored loads above the gravity anchor capacity is not of sufficient duration to move the gravity clumps more than 1-2m, as presented in Section 13.

Consideration 3: The Actual Feasible time history of loads

- The loads are governed by Wave/Wind/Current combinations which are always of short duration of less than 15 minutes.
    - Wave/Wind against Current – increases height and wave steepness (with height limited due to steepness causing breaking), shortens wave period
    - Wave/Wind with Current – reduces wave height and steepness
    - Wave/Wind with no Current – allows for the largest waves

Consideration 4: The monitoring regime on the platform

- The platform will be constantly monitored to assess the position via GPS. Positional readings can be used to assess loads and to correlate the model
- There will be load cells within the northerly mooring connection point.
- As well as correlating the model the offset and loads can be used to assess how reasonable the modelled loads are. In the event that the loads assessed during the initial summer testing programme are higher than the model, additional chain can be added to the gravity anchors.

Consideration 5: The friction coefficient of 0.80 proposed

- Formal drag tests have been performed confirming a friction coefficient above 0.85.
- Drag tests on other projects on the site have asserted coefficients for chain clumps above 1.0
- The ability of the chain clump to mould with the seabed is good and therefore the restraint to dragging of such a large assembly of chain as 150-200t can be taken with high confidence.

6.6 ACCIDENTAL LIMIT STATE

The ALS load cases select the most onerous 4 cases from the ULS results and remove a mooring line which results in the largest load.

The ALS checks following the same process as the ULS checks with slightly reduced safety factors.

Consequence Class	Type of Analysis	Partial Safety Factor on mean tension γ_{mean}	Partial Safety Factor on dynamic tension γ_{dyn}
1	Dynamic	**1.00**	**1.10**
2	Dynamic	1.00	1.25
1	Quasi-Static	1.10	
2	Quasi-Static	1.35	

Table 6-2 – ALS Partial Safety Factors as per Reference 2, the bold values denoting the factors used in this analysis.

7. PLATFORM MODELLING

7.1 GENERAL

The platform is made up of 3 blocks – Upper, Vertical and Lower, Figure 7-1. A schematic showing the critical dimensions is shown in Figure 7-2. A summary of the device properties is given in Table 7-1

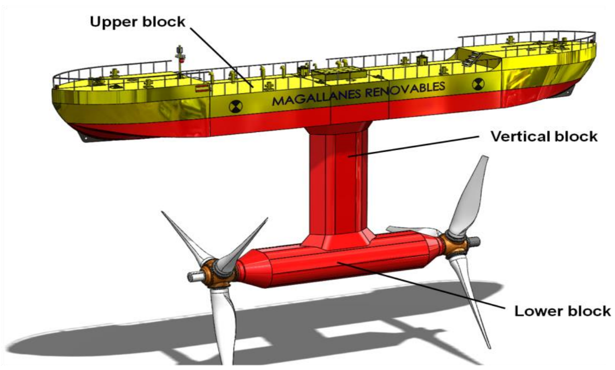


Figure 7-1 - Description of the platform components

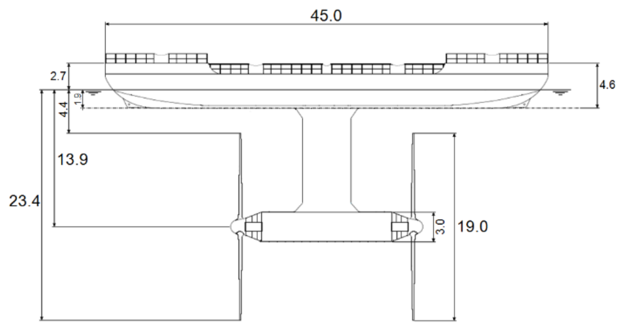


Figure 7-2 - Indicative overall dimensions of the platform

Item	Specification
Overall length	45 m
Extreme moulded breadth	6 m
Waterline Length	43.1 m
Operational draught	23.4 m
Above waterline Transverse area	9.72 m^2
Above waterline Longitudinal area	93.62 m^2
Mass (Hull)	644.2 Te

Table 7-1 – Properties of the Platform and Turbine

7.2 UPPER BLOCK

7.2.1 DESCRIPTION

The upper block is the largest part of the platform, through which accessibility is gained for maintenance. It is divided into three main rooms: one room is allocated to pumps and emergency power systems, whereas the other two rooms have been designed for accommodating the transformers, converters, switchgears and electrical panels, in addition to other parts of the electrical and electronic systems. Apart from these three main rooms, there are two inaccessible compartments at both ends of the block which are part of the ballast system which employs fresh water, as well as several tanks in the centre of the block for environmental acceptable lubricant supply and bilge water.

Figure 7-3 – Upper Block

7.2.2 MODELLING

The upper block is subject to both wind and current loading and so is in effect analysed as two parts divided by the waterline.

DIMENSION	VALUE
Beam (m)	6 m
Waterline Length (m)	43.1 m
Draft (m)	1.88 m
Current - Transverse area (Sway)	81.03 m^2
Current - Longitudinal area (Surge)	11.28 m^2
Wind - Transverse area (Sway)	93.62 m^2
Wind - Longitudinal area (Surge)	9.72 m^2

Table 7-2 - Geometry and draft of Magallanes hull used for derivation of Longitudinal and Transverse areas used in drag calculations

7.2.3 UPPER BLOCK - WIND COEFFICIENTS

The wind loads on the hull have been calculated by two methods, one using the OCIMIF database and the other using the method detailed in DNV-RP-C205, Section 5 which states that the wind force, Fw, on a structure can be calculated according to:

$$F_W = CqSsin\alpha$$

Where:

C = the shape coefficient

S = projected area of the member normal to the direction of the force

α = the angle between the direction of the wind and the axis of the exposed surface

q = basic wind pressure

$$q = \frac{1}{2}\rho_a U_{T,z}^2$$

ρ_a = density of air

$U_{T,z}$ = wind velocity averaged over a time T at a height z meter above water level

OCIMF drag coefficients were used in the analysis.

Wind coefficients				
Headings	Ct	Cx	Cy	Cz
0	-1	-1	0	0
20	-1.1	-0.8	-0.3	0.029
40	-1.4	-0.6	-0.7	0.075
60	-1.4	-0.3	-1	0.123
80	-1.2	-0.1	-1.1	0.156
100	-1.2	0.13	-1.1	0.189
120	-1.4	0.28	-1.1	0.246
140	-1.4	0.52	-0.9	0.243
160	-1.1	0.74	-0.4	0.165
180	-1	0.75	0	0
200	-1.1	0.74	0.43	-0.17
220	-1.4	0.52	0.87	-0.24
240	-1.4	0.28	1.08	-0.25
260	-1.2	0.13	1.14	-0.19
280	-1.2	-0.1	1.14	-0.16
300	-1.4	-0.3	1.01	-0.12
320	-1.4	-0.6	0.69	-0.08
340	-1.1	-0.8	0.31	-0.03
360	-1	-1	0	0

Table 7-3 – *Wind Coefficient for the Hull (OCIMF – Database)*

7.2.4 UPPER BLOCK - CURRENT COEFFICIENTS – SURGE & SWAY

Initially the surge and sway coefficients were initially calculated using the OCIMF database and DNV-RP-C-205, as well as with CFD.

In the final analysis, to achieve a level of certainty, tow tests were performed near Vigo. These results were found to nearly validate CFD results and are presented in Section 7.6.

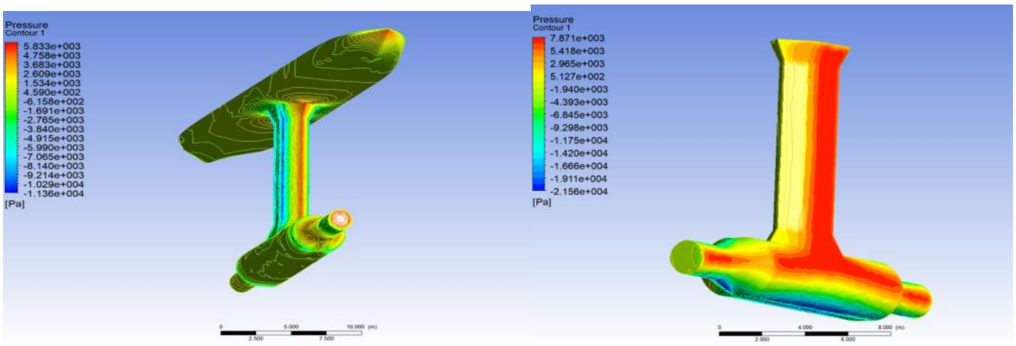


Figure 7-4 - CFD study to derive head and beam sea current coefficients

Coefficients at Oblique headings were derived using API recommended practice (Equation C.8 as presented below), first deriving a total force and a resulting C_T.

$$F_{\emptyset} = F_x\left[\frac{2cos^2\emptyset}{1+cos^2\emptyset}\right]+F_y\left[\frac{2sin^2\emptyset}{1+sin^2\emptyset}\right]$$

7.2.5 HULL CURRENT COEFFICIENTS – YAW

The yaw moment rate is calculated as:

$$M_Z = 0.5\rho|\omega|\omega K_{YAW}$$

Where:

$$K_{YAW} = C_D\frac{DL^4}{32}$$

Taking C_D as

$$C_Y = 2.04\ M_Z = 0.5\rho|\omega|\omega \times 2.04 \times \frac{1.88\times 43.1^4}{32} = 0.5\rho|\omega|\omega\ 413568 \quad (1)$$

$$\therefore Yaw\ Rate\ Moment\ Factor = \ 413568m^5$$

The Yaw moment due to the Yaw Rate Moment at each angle of inclination is taken as:

$$M_Z = 0.5C_{YAW}\rho V^2 A_{YAW}$$

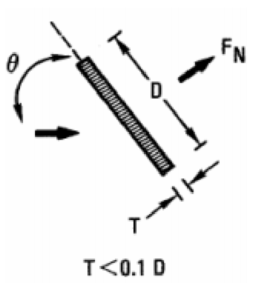
Assuming rectangular underwater cross section of the platform:

$$A_{YAW} = A_{SWAY} \times Centroid\ of\ half\ submerged\ area = 190.2 \times 21.7/2 = 2063.7m^3$$

The yaw coefficients are calculated using the yaw rate moment factor by transferring the normal component of a 1m/s current velocity at 45degrees of incident flow into an equivalent rotational frequency, because the yaw moment is a maximum when the oblique angle is 45 degrees and zero and purely head or stern seas.

With an incident flow of 1m/s the resulting equivalent frequency (at the centroid of the forward or aft half of the transverse area = 21.7/2) is 0.06rad/s. The resulting Mz using equation (1) is 900kNm. The resulting Cmz is 0.85 at 45degrees using the yaw area of 2063.7m^3. The coefficients for the remaining headings are derived assuming a sinusoidal relationship for each other heading and are reported in Table 7-7.

9. Thin flat plate inclined to flow



$$C_N = \begin{cases} 2\pi\tan\theta, \theta < 8^\circ \\ \dfrac{1}{0.222 + 0.283/\sin\theta}, 90^\circ \geq \theta > 12^\circ \end{cases}$$

$$C_L = C_N \cos\theta$$

$$C_D = C_N \sin\theta$$

Figure 7-5 - Lift & Drag coefficient on a flat plate supproting the assertion of a maximum yaw coefficient at 45 degrees

DEVICE HEADING	CMZ
0	0.00
10	-0.29
20	-0.55
30	-0.74
40	-0.84
45	**-0.85**
50	-0.84
60	-0.74
70	-0.55
80	-0.29
90	0.00
100	0.29
110	0.55
120	0.74
130	0.84
135	**0.85**
140	0.84
150	0.74
160	0.55
170	0.29
180	0.00

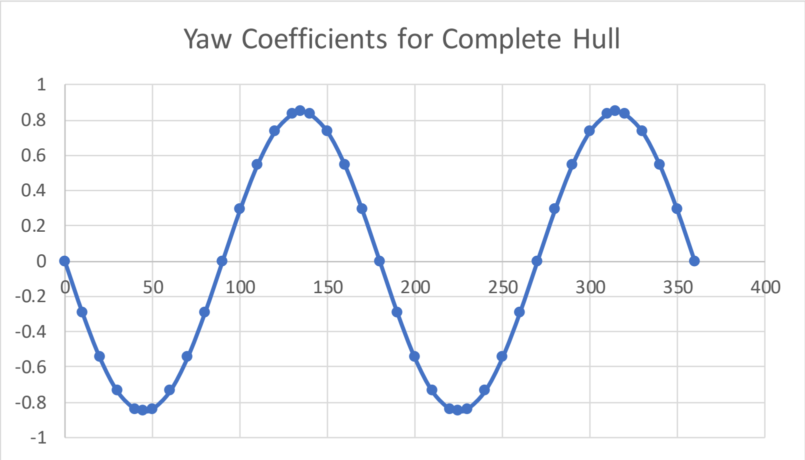


Figure 7-6 - Current Yaw Coefficients derived as per Section 7.2.5

7.3 VERTICAL BLOCK (MAST)

7.3.1 DESCRIPTION

The Vertical Block fixes the lower block to the upper block. It is a hollow space through which the communication and low-voltage cables connect the equipment housed in the lower block with the parts of the systems within the upper block. Rigid pipes for environmentally acceptable lubricant supply and draining, among others, are also installed in the vertical block.

DIMENSION	VALUE
Frontal Width	2.0 m
Height (m)	10.53 m
Transverse Width (m)	4.84 m
Transverse area (Sway)	52.4 m^2
Longitudinal area (Surge)	24.8 m^2

Table 7-4 - Geometry and draft of Magallanes hull used for derivation of Longitudinal and Transverse areas used in drag calculations

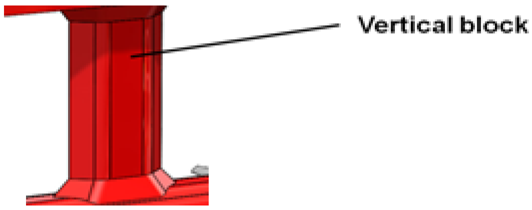


Figure 7-7 - Description of the platform components

7.3.2 MODELLING- CURRENT COEFFICIENTS

In the same way as the upper block, the lower block was initially calculated using DNV-RP-C205 in the method is presented below. Subsequently tow tests were carried out which provided a more reliable set of results, as presented in Section 7.6.

Considering the mast design" drawing, and DNV-RP-C205 [5], Appendix E, Table E-1, the strut (viewed from the front) can be assumed to be a diamond with rounded corners, Figure 7-8

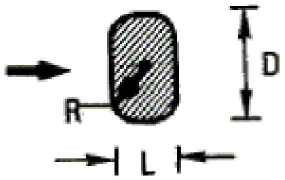


Figure 7-8 - Diamond with rounded corners (left- excerpt from DNV-RP-C205)

The strut has the following properties viewed from head on:

$L_0/D_0 = 2.42$ $\quad$ $R/D_0 = 0.5/4.84$

Therefore, interpolating data from DNV-RP-C205, the drag coefficient in head seas is 0.8 (based on the frontal width). The strut has the following properties viewed from the side:

$L_0/D_0 = 0.41$ $\quad$ $R/D_0 = 0.5/2$

Therefore, from DNV-RP-C205, the drag coefficient in beam seas is 1.15 (based on the longitudinal width).

7.4 LOWER BLOCK

7.4.1 DESCRIPTION

The Lower Block is significantly smaller than the upper block and houses the mechanical system. The most relevant components placed in this block are the main shafts, ball bearings, gear boxes and generators. The platform is fitted with two counter-rotating rotors. As a result, all components of the mechanical system shall be in duplicate (one for each rotor).

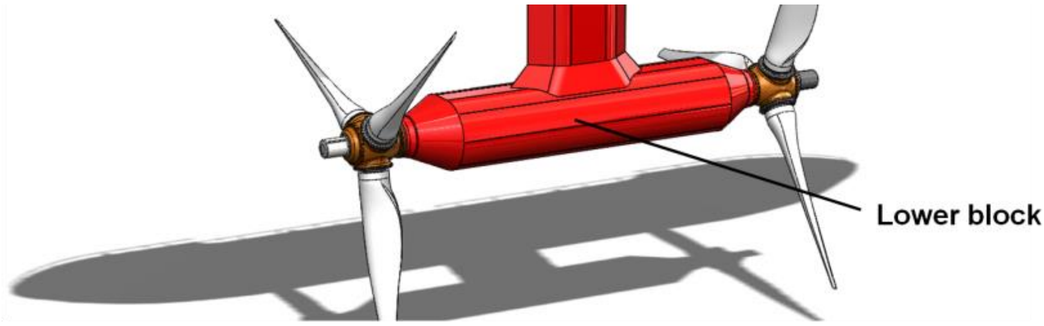


Figure 7-9 - Description of the platform components

DIMENSION	VALUE
Diameter (m)	3m
Length (m)	16.8m
Transverse Area (sway) (including hub)	56.8m^2

7.4.2 MODELLING- CURRENT COEFFICIENTS

In the same way as the upper block, the lower block was initially calculated using DNV-RP-C205 in the method is presented below. Subsequently tow tests were carried out which provided a more reliable set of results, as presented in Section 7.6 and these values were not used except in the derivation of the centre of drag.

Considering the nacelle dimensions, and DNV-RP-C205 [5], Appendix E, Table E-1, the nacelle can be assumed to be an ellipse with D/L =1 and resulting Cd of 1.0 Figure 7-10

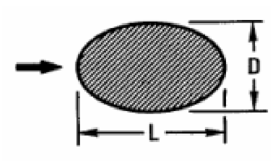
14. Ellipse	D/L	C_D (R_e ~10^5)
 D L	0.125 0.25 0.50 1.00 2.0	0.22 0.3 0.6 1.0 1.6

Figure 7-10 – Ellipse drag coefficients (Excerpt from DNV-RP-C205)

For the head on coefficient for the nacelle, although cone shaped the longitudinal coefficient has been treated as a flat plate with a Cd of 1.9. Although the shape is closer to a round noses section with a coefficient of less than half this higher coefficient may account for additional drag elements as part of the hub.

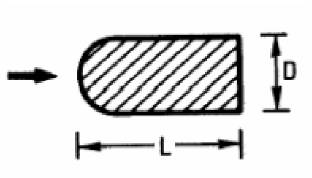
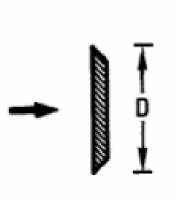
7. Rounded nose section	L/D	C_D
	0.5 1.0 2.0 4.0 6.0	1.16 0.90 0.70 0.68 0.64
8. Thin flat plate normal to flow 	$C_D = 1.9,\ R_e > 10^4$	

Figure 7-11 – Drag coefficient for round nosed seciton and flat plate (Excerpt from DNV-RP-C205)

7.5 COMBINED PLATFORM (UPPER AND VERTICAL BLOCK)

7.5.1 CURRENT COEFFICIENTS - ANALYTICAL METHOD

The Table 7-5 presents the individual area and drag coefficients.

					Combined Current coefficients					Z Ref. Point
Heading (deg)	Ct hull	Ct strut	At hull	At strut	Ct	Cx	Cy	Cz	At	Z
0	0.1	0.8	11	32	0.62	0.62	0	0	43.1	-3.63
20	0.2	0.99	28	53	0.72	0.68	0.25	-0.03	80.2	-3.13
40	0.38	1.26	56	87	0.92	0.71	0.59	-0.1	143.1	-2.84
60	0.49	1.31	74	106	0.97	0.49	0.84	-0.19	180.3	-2.72
80	0.52	1.18	80	109	0.9	0.16	0.89	-0.24	189.8	-2.63
100	0.52	1.18	80	109	0.9	-0.16	0.89	-0.24	189.8	-2.63
120	0.49	1.31	74	106	0.97	-0.49	0.84	-0.19	180.3	-2.72
140	0.38	1.26	56	87	0.92	-0.71	0.59	-0.1	143.1	-2.84
160	0.2	0.99	28	53	0.72	-0.68	0.25	-0.03	80.2	-3.13
180	0.1	0.8	11	32	0.62	-0.62	0	0	43.1	-3.63
200	0.2	0.99	28	53	0.72	-0.68	-0.25	0.03	80.2	-3.13
220	0.38	1.26	56	87	0.92	-0.71	-0.59	0.1	143.1	-2.84
240	0.49	1.31	74	106	0.97	-0.49	-0.84	0.19	180.3	-2.72
260	0.52	1.18	80	109	0.9	-0.16	-0.89	0.24	189.8	-2.63
280	0.52	1.18	80	109	0.9	0.16	-0.89	0.24	189.8	-2.63
300	0.49	1.31	74	106	0.97	0.49	-0.84	0.19	180.3	-2.72
320	0.38	1.26	56	87	0.92	0.71	-0.59	0.1	143.1	-2.84
340	0.2	0.99	28	53	0.72	0.68	-0.25	0.03	80.2	-3.13
360	0.1	0.8	11	32	0.62	0.62	0	0	43.1	-3.63

Table 7-5 – Current Coefficient for the combined Hull (i.e. Upper Block and Strut)

		Upper Block	Vertical Block	Lower Block	Total	
Head	**Area**	11.28	24.8	7.02	43.1	m^2
Beam	**Area**	81.03	52.4	56.77	190.2	m^2
Head	**Cd**	0.1	0.8	1.9	0.80	
Beam	**Cd**	2	1.15	1	1.47	
Head	**CoP (z)**	0.94	-5.75	-12	-7.96	m
Beam	**CoP (z)**	0.94	-5.75	-12	-3.14	m

Table 7-6 – Calculation of the Centre of pressure used in the analysis. In the Orcaflex model the average of the head sea and beam sea CoP(z) value was used.

7.6 CURRENT COEFFICIENTS - EMPIRICAL METHOD

In addition to the above analysis to derive current coefficients, tow tests have been conducted to try and improve and verify the drag coefficients, see Figure 7-12. Results from the trials are given below, Figure 7-13, where Rt is the reaction in the tow line and V is the velocity.

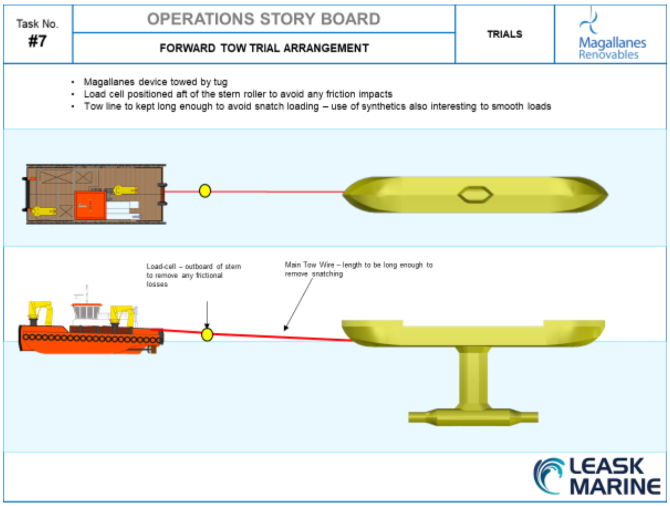


Figure 7-12 –Drag Force (Forward) Tow Test Set up

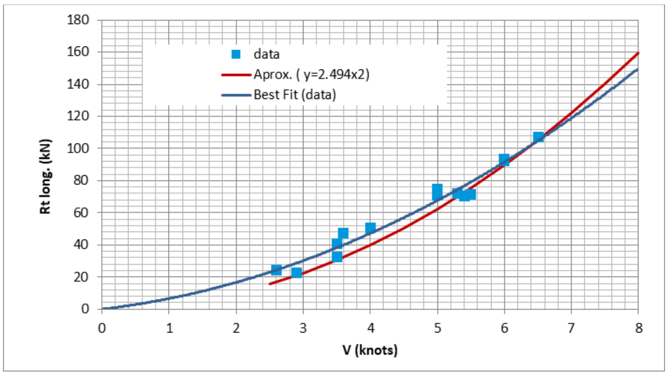


Figure 7-13 – Longitudinal Drag Force vs Velocity

Assuming the relationship between the longitudinal reaction force is proportional to velocity^2, such that Rt = $k.v^2$, then k = 2.494. Using this assumption and solving for k, gives a Cd of 0.46, see Figure 7-14. This assumption looks satisfactory based on Figure 7-13, but looks under conservative for low velocities.

However most of the critical (ULS) load cases are at higher velocities, (7knots), and operationally when the turbines are experiencing their maximum thrust (@ 2.5m/s ~ 5knots). At this velocity the drag coefficient is 0.49.

This is lower than the 0.62 calculated in Section 0 above. However, it is justified to use this as it is based on real data.

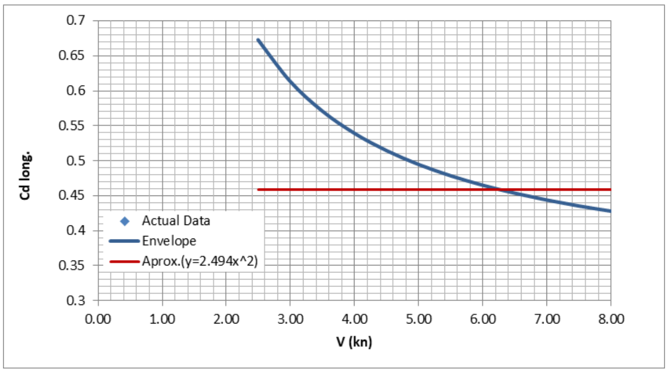


Figure 7-14 – Coefficient of Drag (Longitudinal) based on Actual Data, Best Fit and a constant Cd proportional relationship

Similarly, the transverse drag has been derived in the same way, see Figure 7-16. A coefficient of drag is taken to be 2.04 based on these trials. This seems conservatively large compared to the calculated result using DNV-RP-C205 and OCIMF. However, it does tie well with CFD analysis carried out and, on the basis of real results and being the most conservative, this value is selected.

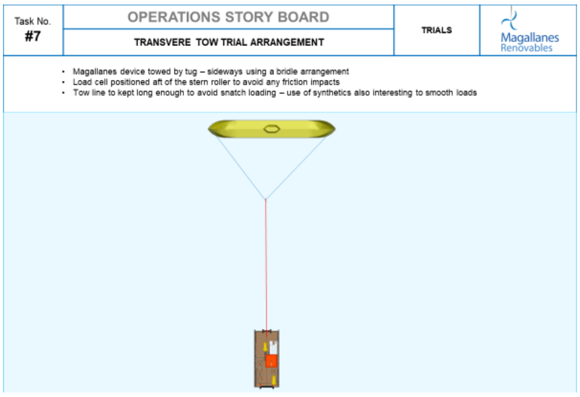


Figure 7-15 – Coefficient of Drag (Beam) based on Actual Data, Best Fit and a constant Cd proportional relationship

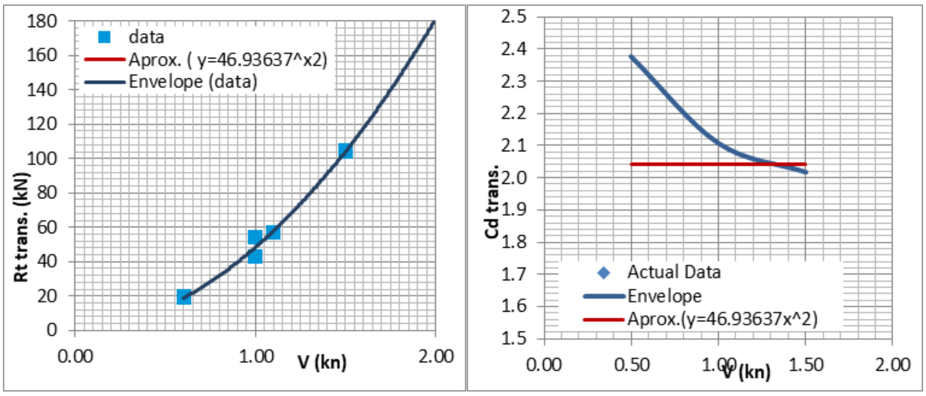


Figure 7-16 – Drag Force and Coefficient of Drag (Longitudinal) vs Velocity based on Actual Data, Best Fit and a constant Cd proportional relationship

7.7 SUMMARY OF COMBINED PLATFORM

Based on the data above the following, Table 7-4 is used for the drag coefficients of the combined upper block and vertical block.

Heading (deg)	Ct	Cx	Cy	Cmz	Heading (deg)	Ct	Cx	Cy	Cmz
0	0.49	0.49	0.00	0.00	**180**	0.49	-0.49	0.00	0.00
20	0.89	0.83	0.30	-0.03	**200**	0.89	-0.83	0.30	0.03
40	1.56	1.19	1.00	-0.10	**220**	1.56	-1.19	1.00	0.10
60	1.94	0.97	1.68	-0.19	**240**	1.94	-0.97	1.68	0.19
80	2.04	0.35	2.01	-0.24	**260**	2.04	-0.35	2.01	0.24
90	2.04	0.00	2.04	-0.25	**280**	2.04	0.35	2.01	0.24
100	2.04	-0.35	2.01	-0.24	**300**	1.94	0.97	1.68	0.19
120	1.94	-0.97	1.68	-0.19	**320**	1.56	1.19	1.00	0.10
140	1.56	-1.19	1.00	-0.10	**340**	0.89	0.83	0.30	0.03
160	0.89	-0.83	0.30	-0.03	**360**	0.49	0.49	0.00	0.00

Table 7-7 – *Coefficient of Drag based on tow tests*

DIMENSION	VALUE
Longitudinal area	190.2 m^2
Transverse area	43.1 m^2

Table 7-8 – Combined Area of hull and spar used in drag calculations

7.7.1 HYDROSTATIC & HYDRODYNAMIC PROPERTIES

The hydrostatic restoring coefficients were derived using the MOSES. The software was used to generate the hydrodynamic coefficients namely:

- Added Mass & Damping matrices
- Wave Load RAOs
- Mean Drift QTFs
- Hydrostatic Restoring Coefficients

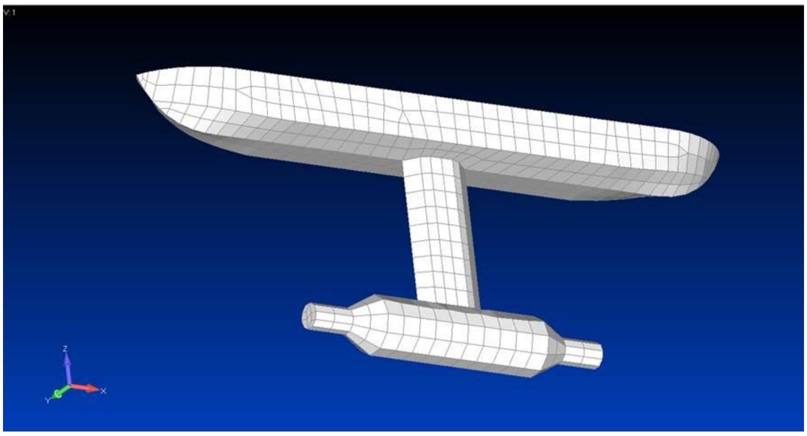


Figure 7-17 – Model of Magallanes Platform, (Upper, Vertical and Lower Block)

Property	Value
Displacement	644.2 te
Draft	1.88 m
VCB	-3.229 m
GM0	1.048 m
XoG	0.04 m
YoG	0.01 m
ZoG	-3.28 m
KG	-3.28 m
Ixx	7434
Iyy	52745
Izz	48796
Kxx	5.5606 m
Kyy	14.8121 m
Kzz	14.2468 m
Kxy	0.3477 m

Table 7-9 – Mass Properties for Hydrostatic restoring coefficient calculation

8. TURBINE MODELLING

8.1 TURBINES

The turbine blades have variable blade pitch system with which are able to turn on their axis in order to optimise energy capturing.

There are three blades on each rotor and two rotors on each end of the lower block. The rotor hubs are separated 16.80m from each other, with the shafts rotating in opposite directions in normal operation.

PROPERTY	VALUE
Diameter	19m
Swept Area	283.5m^2
Theoretical Available Power	2.27 MW
Max Power at Betz Limit(16/27)	1.35 MW
Tip Speed at Nominal Speed	16.9m/s
Rev per second	0.281 rev/s
Generation Torque at Nominal Power	567 kNm
Hub Centreline Depth	14.5m
Root Radius	0.6m
Rotor Speed	16.82 rpm

Table 8-1 – Dimensional, Mass and Inertial properties

8.1.1 TURBINE MODELLING

The thrust force due to the turbines is modelled by simplifying the blade swept area as a disc with diameter of the swept area and a variable coefficient to represent the operating of survival drag loads using the equation:

$$F_D = C_D \times 0.5 \times \rho \times A \times V^2$$

The turbine is therefore effectively modelled as an imperfect disc. The imperfection is defined by a drag coefficient. Similarly, the added mass coefficient can be factored in the same way C_a is factored proportionally with Cd.

In terms of modelling relevant for the mooring analysis, there are three extreme conditions for the turbines:

- Condition 1 - Normal Operating Condition - 2.5m/s
- Condition 2 - Normal Operating Condition - 3.6m/s
- Condition 3 - Stopped - Either not sufficient current or in Survival mode

A summary of the coefficients is presented in Table 8-2 below.

- A description of the derivation of the normal operating condition drag coefficient is presented in Section 8.1.2
- A description of the derivation of the survival condition drag coefficient is presented in Section 8.1.3.

Condition Number	Condition Description	V [m/s]	Radius [m]	Swept Area [m²]	C_D
1	Operating	2.5	9.5	283.5	0.71
2	Operating	3.5	9.5	283.5	0.16
3	Survival	-	1.61	283.5	0.001

Table 8-2 – Drag, Added Mass coefficients and swept areas for various Operating and Survival conditions

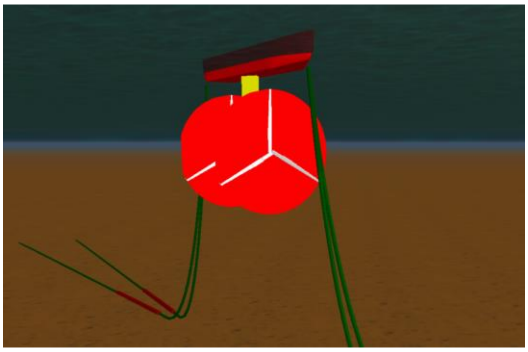


Figure 8-1 - Schematic of blade swept area and coefficient modelling

8.1.2 CONDITION 1 & 2 - NORMAL OPERATING CONDITION

It is noted that under normal operating conditions, as the current speed increases, the blades pitch to give the optimum energy to the generator – this gives a varying drag and load profile. The maximum thrust is expected at the rated speed, 2.5m/s, above this the blades feather and load shed reducing the axial thrust.

Two methods of calculating the thrust (or effective drag coefficient) are shown in Reference 18. Further information has been provided (Ref [18]) – which gives the total thrust force on the rotor at 2.5m/s of 645kN. This means the equivalent Cd for a swept area of 283.5 m^2 to achieve this thrust is given by

$$C_d = \frac{T}{{}^{1}/_{2}\,\rho S v^2}$$

Where:

T = Thrust on Rotor — S = Swept Area

v = water velocity (2.5m/s) — ρ = density of sea water

Then: $C_d = 0.71$ This is the coefficient of drag at 2.5m/s.

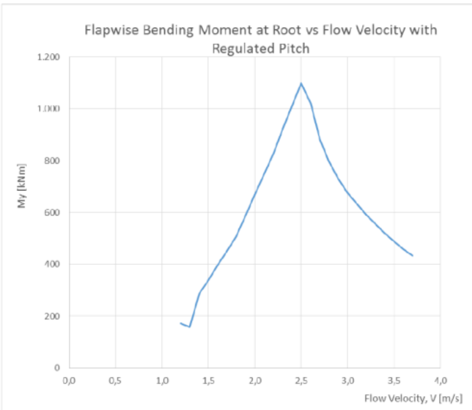
As discussed previously, as the velocity increases, the thrust reduces. Figure 8-2 shows the flapwise bending moment on the blades as they pitch, with this drop in bending moment and load, once rated power (2.5m/s) is reached. Using this graph, it is estimated that the bending moment at the root is 1090 kNm at nominal speed (2.5 m/s), this reduces to 480kNm at 3.5 m/s. Therefore, the coefficient of drag can be reduced by the same amount. Therefore, the coefficient of drag at 3.5m/s is given by

$$C_d = \frac{645 * 480}{1090}\frac{1}{{}^{1}/_{2}\,\rho S v^2}$$

Where, S, ρ are as before and v = 3.5 m/s

Then: $C_d = 0.16$

This is the drag coefficient at 3.5m/s. In order to ensure a conservative analysis, the same drag coefficient is used at 3.6m/s.



Values for a single blade and at the root (R1,2 m)

Figure 8-2 – Extract from ref [18]

8.1.3 CONDITION 3 – SURVIVAL

The only other condition where the turbine will be under a braked position is in the event of an accident or survival condition. There are a number of fail-safes in the control system to make sure the blade pitch is matched to the current velocity.

The platform can enter in survival mode by many more reasons like the following:

- High winds.
- High waves.
- Electrical disconnection (in this case the ancillary fuel engine will be switch on).
- Communication drops off.
- Breakage of umbilical cable.
- Breakage of mooring line.
- Fire detection.
- High temperature in the nacelle.
- Heavy entry of water due to a crash.
- Any unknown problem.

In an extreme event a hydraulic accumulator is activated which will bring the blades back to a failsafe position (average angle of attack is 0). With the assistance of the generator this will bring the blades to a stop and reduce the loads on the rotor and the device itself. In this condition the blades will present its lowest projected area.

It is expected that the blade, along its length will have a varying angle of attack and an assumption is made that over the length of the blade the average thickness is 0.3m with a chord length of 1m.

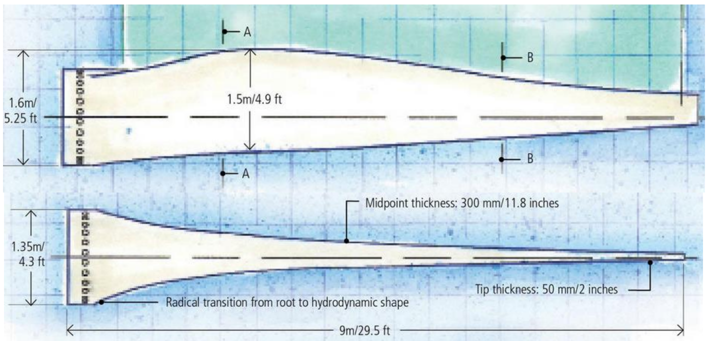


Figure 8-3 – A Tidal Turbine Blade (NOTE shown for example)

From Ref[6, Appendix E 4] – a conservative drag coefficient 0.35 is estimated based on a diameter of 0.3m.

An equivalent disc area would equal 3 off 9m blades with a uniform profile of 0.3m x 1m. The projected area = 3 x 9 x 0.3 = 8.1m^2, or a disc of radius 1.61m. For a swept area of 283.5m^2: $C_D = 0.01$

The added mass C_m is given by Ref[6, Appendix D] $C_m = C_A + 1$

Where Ca is taken as 1.0m assuming an ellipse cross section with a cross section of 0.3 x 1.0m.

9. MOORING

9.1 OVERVIEW

The mooring system utilised 4 catenary legs, two north or the device and two south, attached to two hull attachment points at the bow and stern of the device. The tidal platform is positioned in line with the current flow with two legs continuing this line from the bow and stern and the additional two legs offset by 45 degrees to the west. The final design is shown in Figure 9-1.

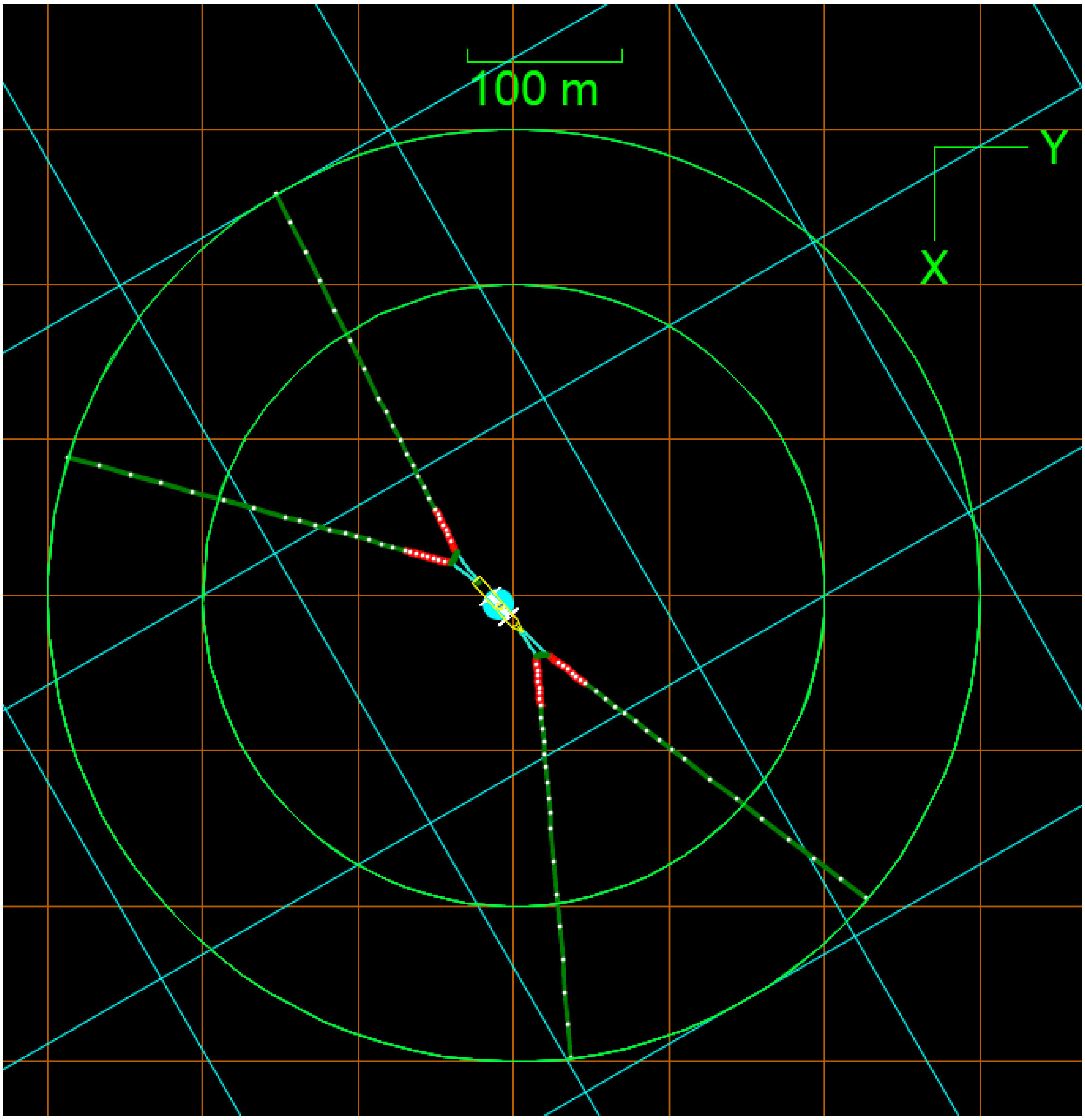


Figure 9-1 - Final Mooring System

9.2 EVOLUTION OF MOORING SYSTEM

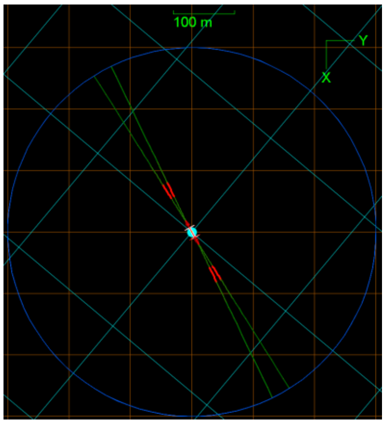
The mooring system was developed as certain aspects of the mooring requirement were optimised. These mooring requirements as summaries as

- Reduce Yaw
- Reduce mooring leg loads
- Reduce maximum excursion

DESIGN EVOLUTION Version 01

Design

Design R01 initial with 4 mooring legs 5 degrees either side off the centre line of the device.



Positives

- Low loads during operational cases

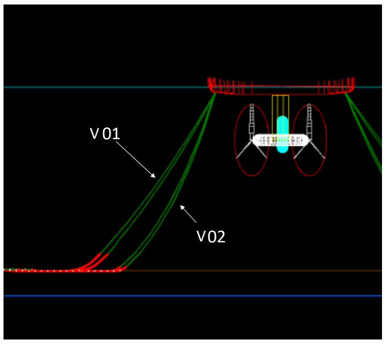
Negatives

- Large Yaw
- Large Excursions

DESIGN EVOLUTION Version 02

Design

Increased pre-tensions in mooring legs by reducing chain length before excursion limiter



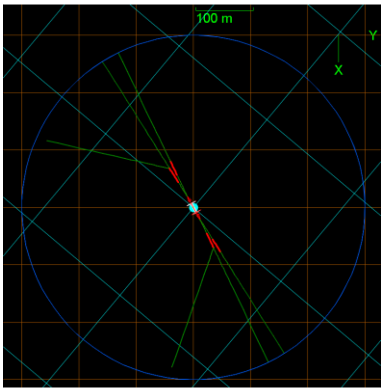
Positives

- Reduced excursion over V01

Negatives

- Increased mooring loads

DESIGN EVOLUTION Version 03



Design

Split west lines below excursion limiter

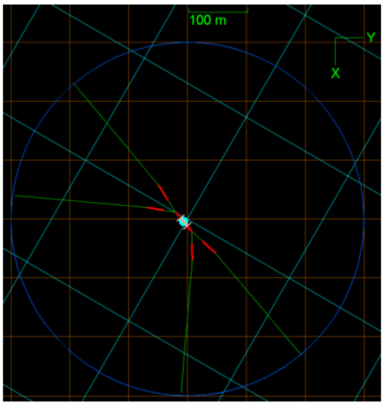
Positives

- Reduced maximum loads over V02
- Reduced Excursion over V02

Negatives

- Increased cost of anchors

DESIGN EVOLUTION Version 04



Design

Offset west lines 45 degrees from centre line of vessel. East lines remain in line with vessel

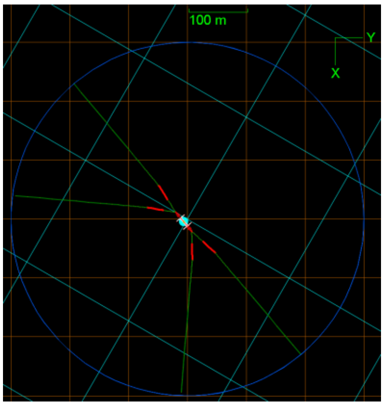
Positives

- Reduced maximum loads over V03
- Reduced cost

Negatives

- Still has large footprint which a future drilled anchor solution can optimise
- Some eccentricty in loads in each line

DESIGN EVOLUTION Version 05



Design

Addition of synthetic to lower catenary. Addition of lower line to above the excursion limiter.

Positives

- Reduced maximum loads over V04
- Greater sharing of maximum load events

Negatives

- Increased procurement costs
- More challenging operational hook up

9.3 MOORING POSITIONS

The proposed mooring plan lies within the FoW Lease Area, as illustrated in Figure 9-2. Final details and the make-up of the mooring lines are yet to be determined.

There are three proposed positions for the centre of the berth.

- **POSITION 1:** EMEC Proposal of berth centre. This increases risk of contact with Berth 3 cable and increases the required dynamic umbilical length by 341m.
- **POSITION 2:** Preferred Position – The centre of the berth 190m from the end of the EMEC Cable Berth 1 cable end

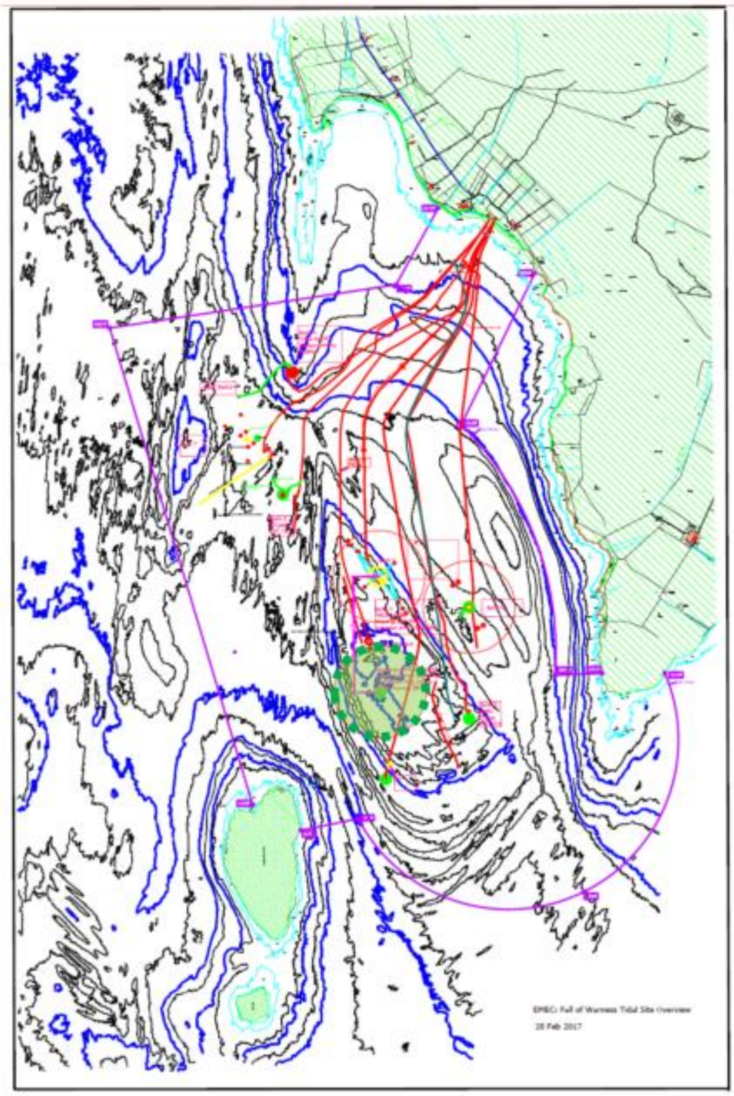


Figure 9-2 - Overview of Fall of Warness, the green highlighted areas showing the location proposed by EMEC for Berth 1

9.3.1 POSITION A

Position A is a revised EMEC Proposal of berth centre (Revised in Email of 20/10/17 compared with 18/09/17). In this proposal, the centre of the berth is now 341m from the end of the EMEC Cable Berth 1 cable end.

- This configuration does not create any risk to nearby berths in the worst single failure (loss of southerly mooring attachment).
- However, with there is a significant deficiency with the location.
- The South-East mooring line passes over the EMEC Cable of Berth 3.
- The only solution is a reduction in the SE anchor leg of at least 112 meters.
- This is not acceptable because the overall mooring stiffness will increase resulting in much higher loads.
- The resulting dynamic cable length of around 500m increases project costs.

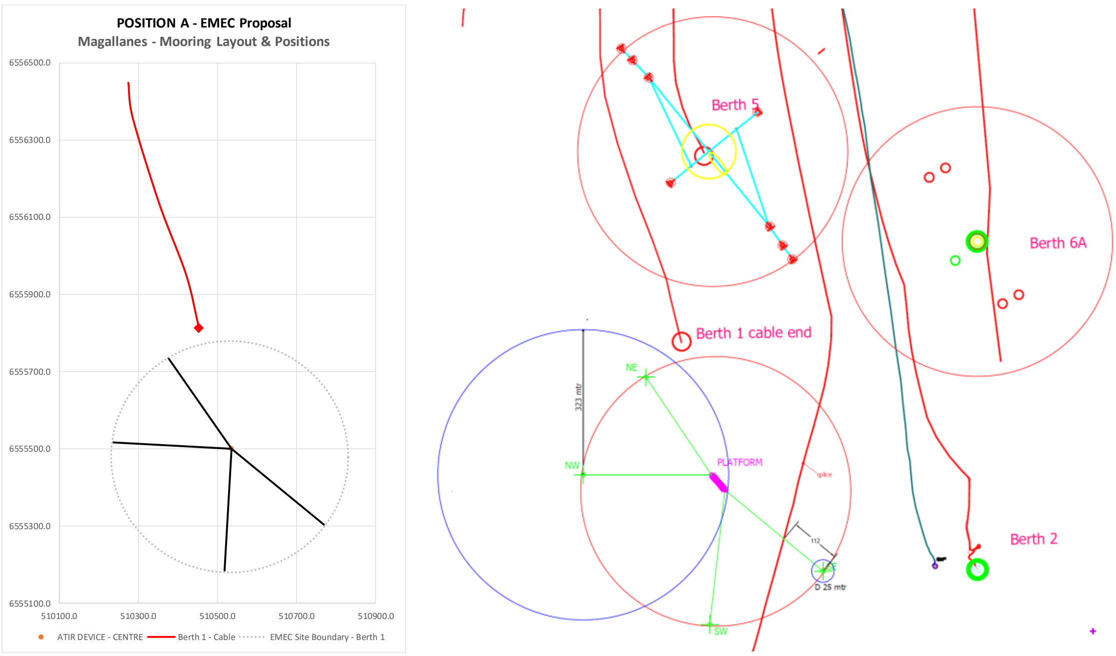


Figure 9-3 – Left – Simple schematic of Initial Mooring Position A following EMEC revised specification of berth centre, Right – Detailed Schematic encompassing other berths - Blue circle indicates maximum academic excursion following worst single failure of southern hull connection)

	Northing	Easting
Device	510536.0	6555500.0
NE Anchor	510376.0	6555734.0
NW Anchor	510236.0	6555517.0
SE Anchor	510769.0	6555303.0
SW Anchor	510518.0	6555184.0

Table 9-1 – Position A - Mooring Positions as Proposed by EMEC

9.3.2 POSITION B

In Position B the Device is shifted 175 meters north and 5m East. With the Magallanes berth radius touching the ScotRenewables permitted berth radius.

- This configuration retains no risk to nearby berths in the worst single failure (loss of southerly mooring attachment).
- However, with the same deficiency with the location remains.
- The South-East mooring line passes over the EMEC Cable of Berth 3.
- The only solution is a reduction in the SE anchor leg of at least 71 meters.
- This is not acceptable because the overall mooring stiffness will increase resulting in much higher loads.
- The resulting dynamic cable length of around 250m improves project costs.

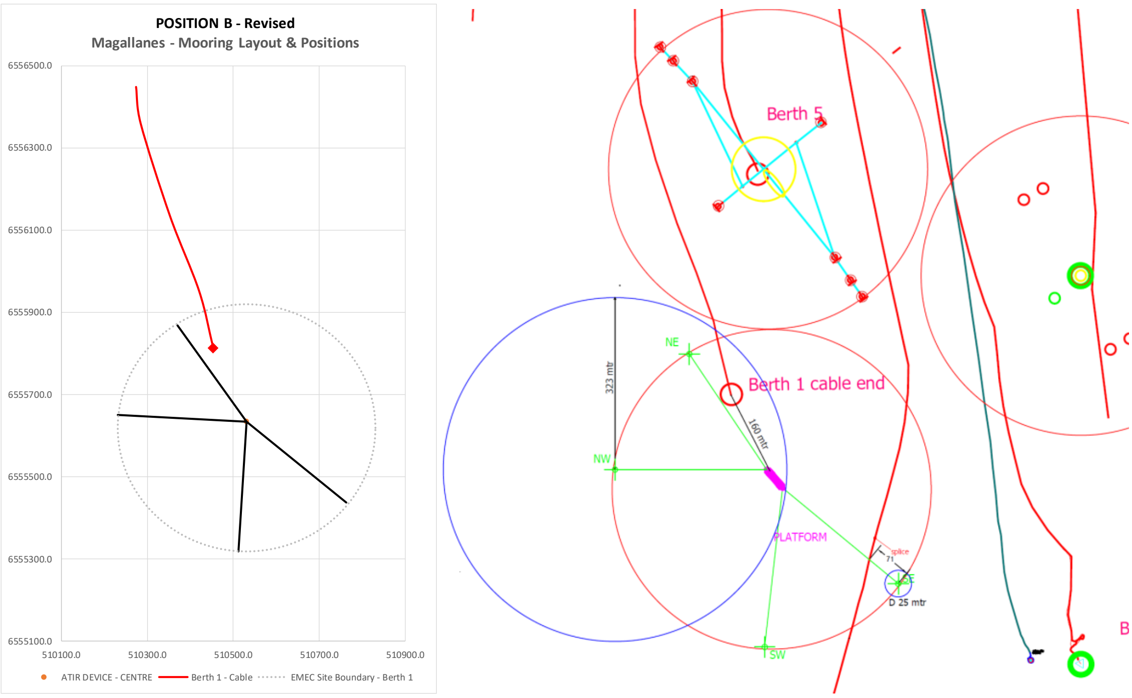


Figure 9-4 – Left – Simple schematic of revised Mooring Position B, Right – Detailed Schematic encompassing other berths - Blue circle indicates maximum academic excursion following worst single failure of southern hull connection)

	Northing	Easting
Device	510536.0	6555655.0
NE Anchor	510376.0	6555889.0
NW Anchor	510236.0	6555672.0
SE Anchor	510769.0	6555458.0
SW Anchor	510518.0	6555339.0

Table 9-2 – Position B - Mooring Positions as Proposed by EMEC

9.3.3 POSITION C

In Position C the Device is shifted 232 meters north and 115 meters west. This configuration is the preferred solution for EMEC approval for the following reasons:

- This configuration retains no risk to nearby berths in the worst single failure (loss of southerly mooring attachment).
- Intact proximity to the Scotrenewables device is 526m. The minimum "academic" damaged proximity is 300m.
- The unacceptable deficiency in Position A and Position B is removed.
- The South-East mooring line is clear of the EMEC Cable of Berth 3 by 25m.
- The resulting dynamic cable length of around 150m improves project costs.

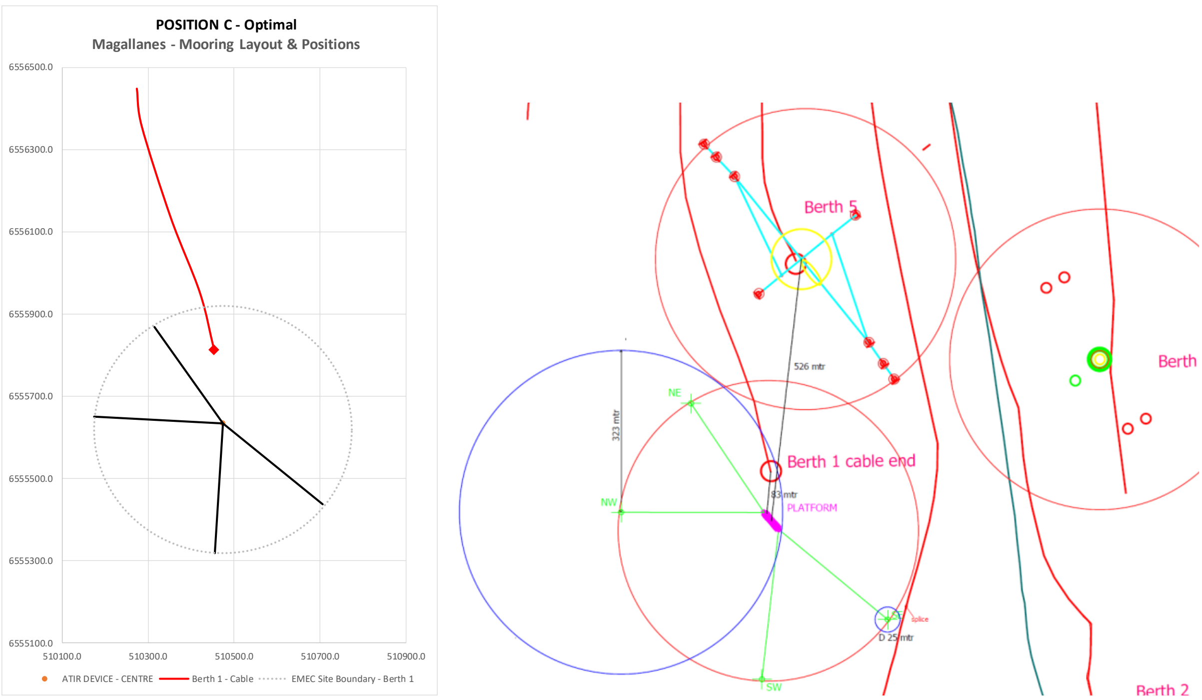


Figure 9-5 – Left – Simple Schematic of preferred Mooring Position B. Right – Detailed Schematic encompassing other berths - Blue circle indicates maximum academic excursion following worst single failure of southern hull connection)

	Northing	Easting
Device	510456.0	6555714.0
NE Anchor	510295.0	6555948.0
NW Anchor	510155.0	6555731.0
SE Anchor	510688.0	6555517.0
SW Anchor	510437.0	6555398.0

Table 9-3 – Position C - Mooring Positions as Proposed by EMEC

9.4 HEADING

The heading of the device was based on the direction of the tidal velocity. Figure 9-6 is repeated here showing a misalignment of EBB and FLOOD of around 10 degrees.

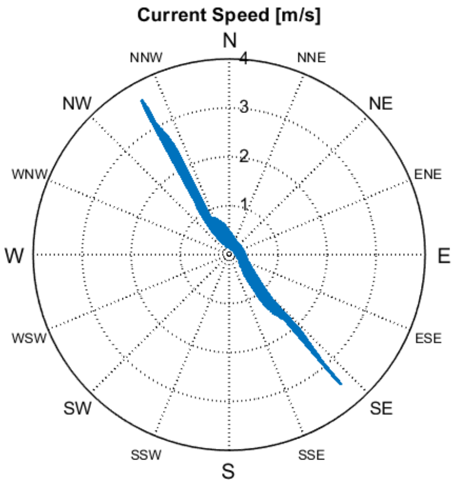


Figure 9-6. Current speed (direction TO) for each direction.

- The EBB current at berth 1 flows almost directly TO heading 331degrees (Figure 10-5)
- The FLOOD current at berth 1 flows almost directly TO heading of 139 degrees (Figure 10-4).
- The EBB current is marginally stronger than the FLOOD current with a maximum flow of 3.61m/s versus 3.5m/s
- On the basis of the above the ATIR device has a heading of 331 degrees

9.5 MOORING SYSTEM FOOTPRINT

A diameter of 600m has been used in the design process to fit the proposed berth location. This is shown schematically in Figure 9-7.

The reason to use the full diameter is to reduce the potential for snatch loading and also to gain the most effective use of the ground chain

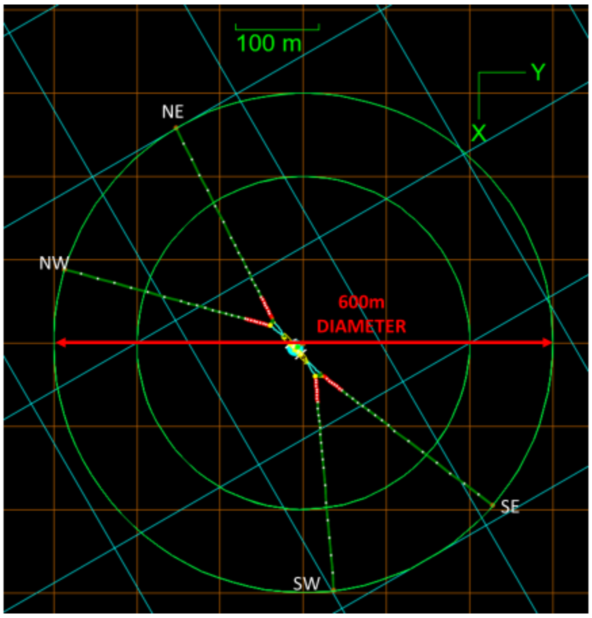


Figure 9-7 - Mooring System Footprint

9.6 MOORING COMPONENTS – FUNCTIONAL & ENGINEERING SUMMARY

9.6.1 SUMMARY

Each of the identical legs uses a catenary system composed of the following:

- **Hull Attachment**
  - A single padeye at the bow and stern, in which a single shackle is connected and from which two mooring lines are attached, see Figure 9-10.

- **Upper Catenary**
  - 5m of 76mm chain
  - 40m of 80mm Bridon Superline Polyester
  - 5m of 76mm chain

- **Excursion Limiter**
  - 30m of 111mm chain or similar arranged in 4 lengths of 30m
  - Provide maximum catenary angle to the seabed
  - Maintain high stiffness within the initial force displacement curve
  - Reduce loads at anchor

- **Ground Chain/Lower Catenary**
  - 225m of 76mm chain
  - Additional weight to reduce anchor loads
  - Reduces anchor size by providing additional weight preventing vertical uplift at anchor and damping larger loads.

- **Anchor**
  - The device is connected to the seabed using four Chain Clump Weights with a total capacity (wet weight) as follows:
    - NW – 90 Te
    - NE – 161 Te
    - SE – 163 Te
    - SW – 137 Te
  - The wet weight capacity is defined by the ULS loads not the ALS loads.
  - Instead of defining the capacity according to the higher ALS loads, it is proposed to link the in-line or end chain clumps such that both anchors may assist in an ALS scenario.
  - End Weight Clumps Anchor (dry-weights)
    - Final weights to be confirmed following design & operational optimisations
      - NE & NW – 75-150Te Chain Clump / leg
      - SE & SW – 75-150Te Chain Clump / leg
  - In Line Clump Weights (dry-weights)
    - Final weights to be confirmed following design & operational optimisations
      - NE & NW – 75-150Te Chain Clump / leg
      - SE & SW – 75-150Te Chain Clump / leg

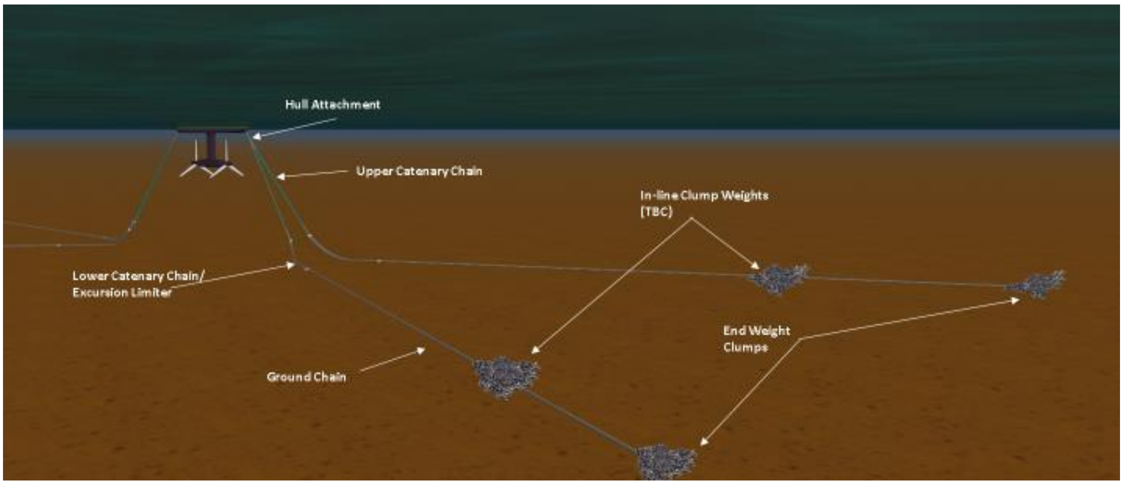


Figure 9-8 – System Breakdown of Magallanes mooring system

A schematic of one mooring leg is shown in Figure 9-9 with the Table 9-4 identifying the components.

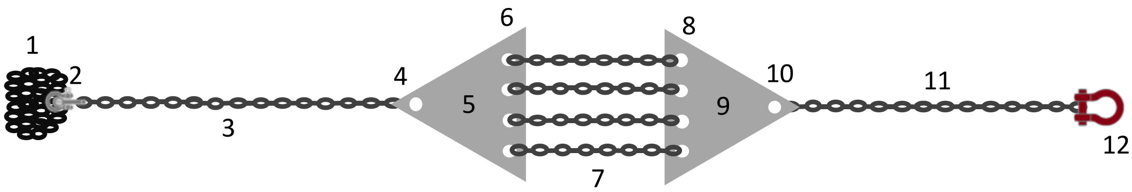


Figure 9-9 - Mooring Component Schematic

SECTION	MOORING COMPONENT	COMPONENT	SWL / MBL
Anchor	1	Chain Clump	N/A
Ground Chain	2	85t SWL Bow Shackle	MBL > 425t
		Spacers	N/A
	3	227m of 76mm Studlink	MBL > 497t (R2 or R3)
Excursion Limiter	4	105mm pins	MBL > 497t
	5	Tri plate	MBL > 497t
	6	105mm pins	MBL > 497t
	7	105mm (25m x 4 in parallel)	MBL > 497t
	8	105mm pins	MBL > 497t
	9	Tri plate	MBL > 497t
	10	105mm pins	MBL > 497t
Upper Catenary	11	5m of 76mm Studlink	MBL > 497t
	12	40m of 80mm Bridon Superline Polyester	MBL > 497t
	13	5m of 76mm Studlink	MBL > 497t
	14	250t WLL bow safety shackle	MBL > 750t
		Spacers	N/A
Attachment	15	Hull attachment point	As per strutural design

Table 9-4 - Mooring Components Summary (Note – specified here is grade R3 but this is not essential. Grade R2 with an MBL of 497Te would be sufficient)

9.6.2 HULL ATTACHMENT POINTS

At each end of the device there is a large reinforced padeye. Structural analysis of this has been performed and presented in Reference 19.

- The ultimate capacity of the mooring attachment points is specified as 350t in Reference 19.
- With a hole diameter of 146mm, the limiting shackle size which can fit into this attachment is a 250t WLL shackle (Figure 9-11).
- Although each shackle already has a safety factor of five, each 250t WLL shackle will be proof loaded (witnessed by LR or similar) to twice the SWL to 500t and provided to the project with an LR witness recertification of 350t WLL.

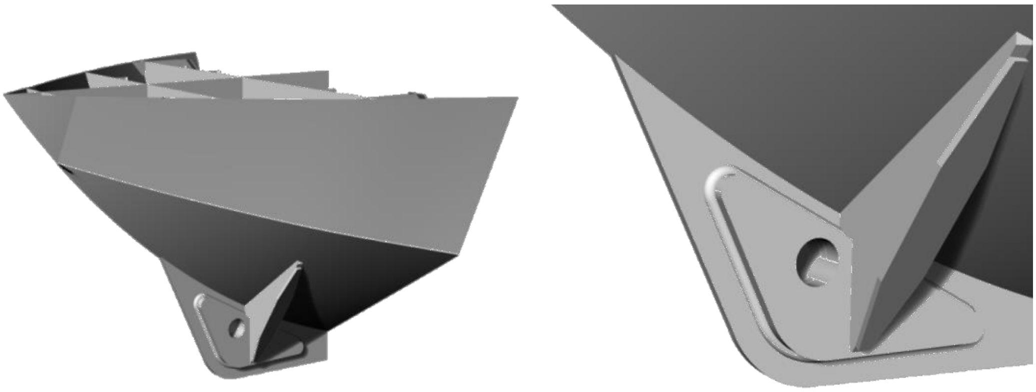
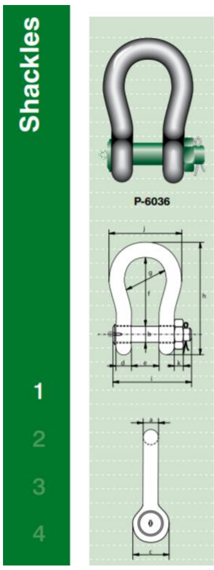


Figure 9-10 – Above – Schematic of upper catenary connecting to padeye at bow or stern



Green Pin® Heavy Duty Shackles
bow shackles with safety bolt

- **Material** : bow and pin alloy steel, Grade 8 quenched and tempered
- **Safety Factor** : MBL equals 5 x WLL
- **Finish** : shackle bow painted silver, pin painted green (120 tons shackle is hot dipped galvanized)
- **Certification** : at no extra charges this product can be supplied with a works certificate, material certificate, manufacturer test certificate, EC Declaration of Conformity and all shackles starting from 150 tons are supplied with a Lloyd's Register of Shipping Certificate on proof load

working load limit	diameter bow	diameter pin	diameter eye	width eye	width inside	length inside	width bow	length	length bolt	width	thickness nut	weight each
	a	b	c	d	e	f	g	h	i	j	k	
t	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	kg
120	95	95	208	91	147	400	238	647	440	428	50	110
150	105	108	238	102	169	410	275	688	490	485	60	160
200	120	130	279	113	179	513	290	838	520	530	60	235
250	130	140	299	118	205	554	305	904	560	565	65	285
300	140	150	325	123	205	618	305	996	575	585	70	340
400	170	175	376	164	231	668	325	1114	690	665	70	560
500	180	185	398	164	256	718	350	1190	720	710	70	685
600	200	205	444	189	282	718	375	1243	810	775	70	880
700	210	215	454	204	308	718	400	1263	870	820	70	980
800	210	220	464	204	308	718	400	1270	870	820	70	1100
900	220	230	485	215	328	718	420	1296	920	860	70	1280
1000	240	240	515	215	349	718	420	1336	940	900	70	1460
1250	260	270	585	230	369	768	450	1456	1025	970	70	1990
1500	280	290	625	230	369	818	450	1556	1025	1010	70	2400

Figure 9-11 - Extract from the Van Beest Green Pin Catalogue

9.6.3 UPPER CATENARY CHAIN

The upper catenary has the function of splitting the mooring legs from the principal shackle at the hull attachment point.

- A 150t WLL shackle, proof loaded with LR or similar witness to 300t and recertified as 250t WLL will link the upper catenary tails with the principal 250t shackle at the hull attachment point.
- Connected to the 250t WLL shackle (the recertified 150t WLL shackle) will be a length of approximately 5m of 76mm studlink R3 grade offshore mooring chain with an MBL in excess of 500t.
- Connected to the upper chain leader will be 40m of 88mm diameter rope which has a MBL of 248 tonnes
- The synthetic will be connected to a 5m chain leader which connects directly to the excursion limiter.
- Above the excursion limiter will be a 7.5m length of chain which links the mooring legs together.

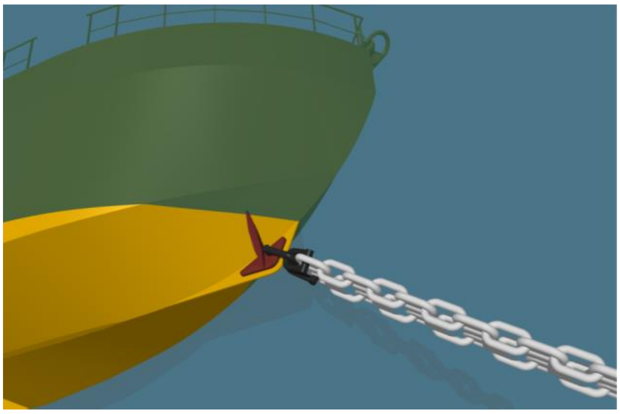


Figure 9-12 - Upper catenary schematic

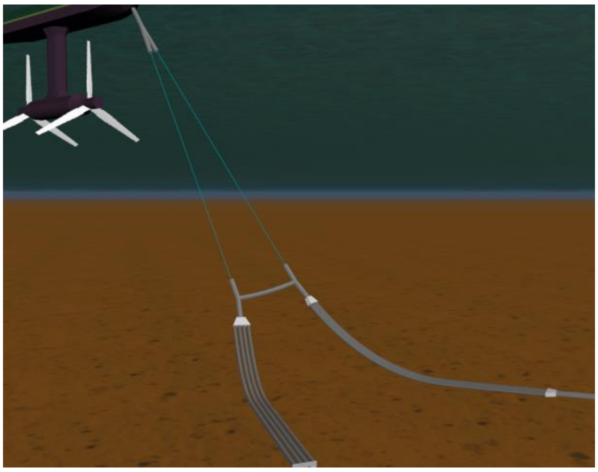
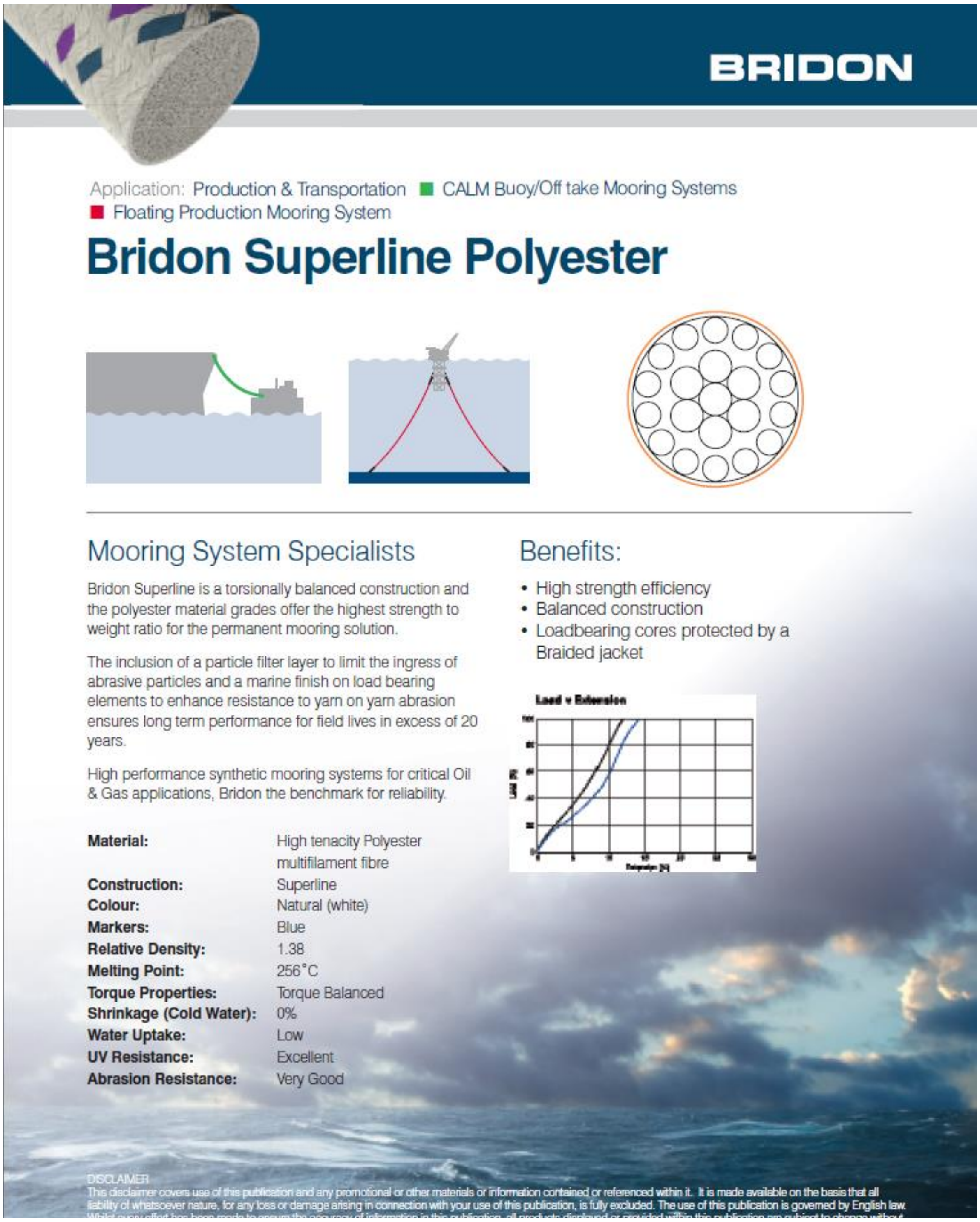


Figure 9-13 - Upper catenary schematic



BRIDON

Application: Production & Transportation ■ CALM Buoy/Off take Mooring Systems
■ Floating Production Mooring System

Bridon Superline Polyester

Mooring System Specialists

Bridon Superline is a torsionally balanced construction and the polyester material grades offer the highest strength to weight ratio for the permanent mooring solution.

The inclusion of a particle filter layer to limit the ingress of abrasive particles and a marine finish on load bearing elements to enhance resistance to yarn on yarn abrasion ensures long term performance for field lives in excess of 20 years.

High performance synthetic mooring systems for critical Oil & Gas applications, Bridon the benchmark for reliability.

Material:	High tenacity Polyester multifilament fibre
Construction:	Superline
Colour:	Natural (white)
Markers:	Blue
Relative Density:	1.38
Melting Point:	256˚C
Torque Properties:	Torque Balanced
Shrinkage (Cold Water):	0%
Water Uptake:	Low
UV Resistance:	Excellent
Abrasion Resistance:	Very Good

Benefits:

- High strength efficiency
- Balanced construction
- Loadbearing cores protected by a Braided jacket

Load v Extension

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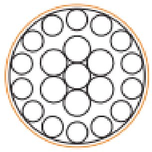
Figure 9-14 - Datasheet 1 for Bridon Superline Polyester



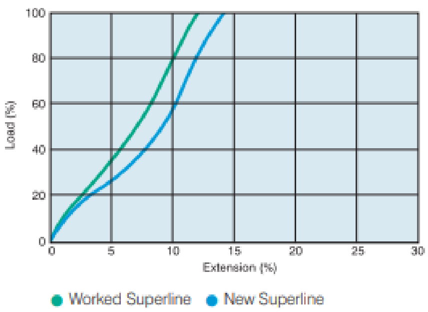
BRIDON SUPERLINE

Polyester

Rope diameter		Rope circumference		Nominal Mass				Minimum breaking force (F min)		
				In air		Submerged				
mm	ins	mm	ins	kg/m	lb/ft	kg/m	lb/ft	kN	Tonnes	Tons (2000lb)
16	5/8	50	2	0.18	0.12	0.05	0.03	79.5	8.10	8.93
18	3/4	57	2 1/4	0.28	0.19	0.07	0.05	114	11.6	12.8
20	13/16	63	2 1/2	0.32	0.22	0.08	0.05	127	12.9	14.2
22	7/8	69	2 3/4	0.36	0.24	0.09	0.06	148	15.1	16.6
24	1	75	3	0.45	0.30	0.11	0.08	181	18.5	20.4
28	1 1/8	88	3 1/2	0.55	0.37	0.14	0.09	221	22.5	24.8
32	1 5/16	101	4	0.77	0.52	0.20	0.13	299	30.5	33.6
36	1 1/2	113	4 1/2	0.87	0.58	0.22	0.15	357	36.4	40.1
40	1 5/8	126	5	1.12	0.75	0.28	0.19	454	46.3	51.0
44	1 3/4	138	5 1/2	1.37	0.92	0.35	0.23	571	58.2	64.1
48	2	151	6	1.65	1.11	0.42	0.28	678	69.1	76.1
52	2 1/8	163	6 1/2	2.06	1.38	0.52	0.35	831	84.7	93.3
56	2 1/4	176	7	2.27	1.53	0.58	0.39	932	95.0	105
60	2 1/2	188	7 1/2	2.48	1.67	0.63	0.42	1030	105	116
64	2 5/8	201	8	2.80	1.88	0.71	0.48	1158	118	130
72	3	226	9	3.91	2.63	0.99	0.67	1648	168	185
80	3 1/8	251	10	4.56	3.06	1.16	0.78	1942	198	218
88	3 1/2	276	11	5.77	3.88	1.46	0.98	2433	248	273
96	3 3/4	302	12	6.64	4.46	1.68	1.13	2776	283	312
104	4 1/8	327	13	7.30	4.91	1.85	1.24	3071	313	345
112	4 3/8	352	14	8.63	5.80	2.19	1.47	3640	371	409
120	4 3/4	377	15	9.50	6.38	2.41	1.62	4022	410	452
128	5	402	16	10.77	7.24	2.73	1.84	4464	455	501
136	5 3/8	427	17	12.55	8.43	3.18	2.14	5219	532	586
144	5 5/8	452	18	13.89	9.33	3.52	2.37	5788	590	650
152	6	478	19	15.20	10.21	3.85	2.59	6357	648	714
160	6 1/4	503	20	16.77	11.27	4.25	2.86	7112	725	799
168	6 5/8	528	21	18.32	12.31	4.65	3.12	7671	782	862
176	6 7/8	553	22	20.54	13.80	5.21	3.50	8613	878	968
184	7 1/4	578	23	22.31	14.99	5.66	3.80	9359	954	1051
192	7 1/2	603	24	24.08	16.18	6.11	4.10	10104	1030	1135

Material: High Tenacity Polyester multifilament fibre
Construction: Superline
Colour: Natural (white)
Markers: Blue
Relative Density: 1.38
Melting Point: 256˚C
Torque Properties: Torque Balanced
Shrinkage (Cold Water): 0%
Water uptake: Low
UV resistance: Excellent
Abrasion Resistance: Very Good

Load v Extension



Figures shown are for guidance purposes only. For details specific to your requirement please contact Bridon.

Figure 9-15 - Datasheet 2 for Bridon Superline Polyester

9.6.4 EXCURSION LIMITER

At the base of the upper catenary chain is an excursion limiter. Example photographs are shown in Figure 9-16. A schematic drawing is shown in Figure 9-18.

In simple terms this is an extremely heavy section of chain just after touchdown.

The excursion limiter is fabricated from 120m of 96-104mm studlink chain or similar arranged in 4 lengths of 30m (this achieves a combined weight of (c.20t of chain including end assemblies).

The following describes the functional requirement of the system:

- Heavy chain to provide the maximum angle of the catenary to the seabed and to maintain as steep as possible the initial force displacement curve of the mooring system.
- This heavier section works as excursion resistance to maintain a small footprint, whilst reducing snatch loading. This is similar to what some term a "parallel chain excursion limiter" used successfully for long duration in mooring offshore floating productions systems.
- If adopting such a solution with more than 2 parallel chains the chains may not be of identical length and thus will experience different tension ranges and slack chain can cause wear issues. However, because in this application the sizing is for strength and not weight and the duration of the mooring is between 1 and 5 years only this is not a risk.

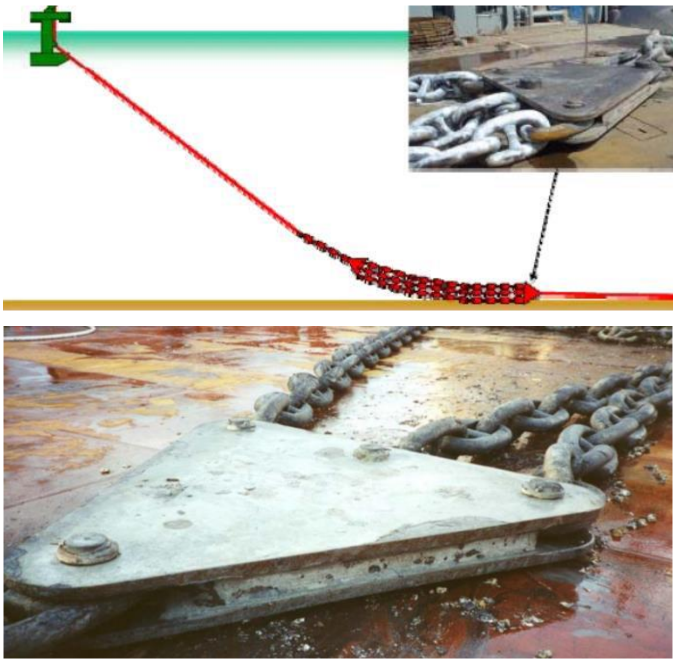


Figure 9-16 – Excursion limiter, as used successful in mooring offshore floating production systems since the 1980s. (Note: Because of the likely drag of the tri-plates on the rocky seabed the design will incorporate steel protection over and around the bolts connecting the chain to each tri-pate)

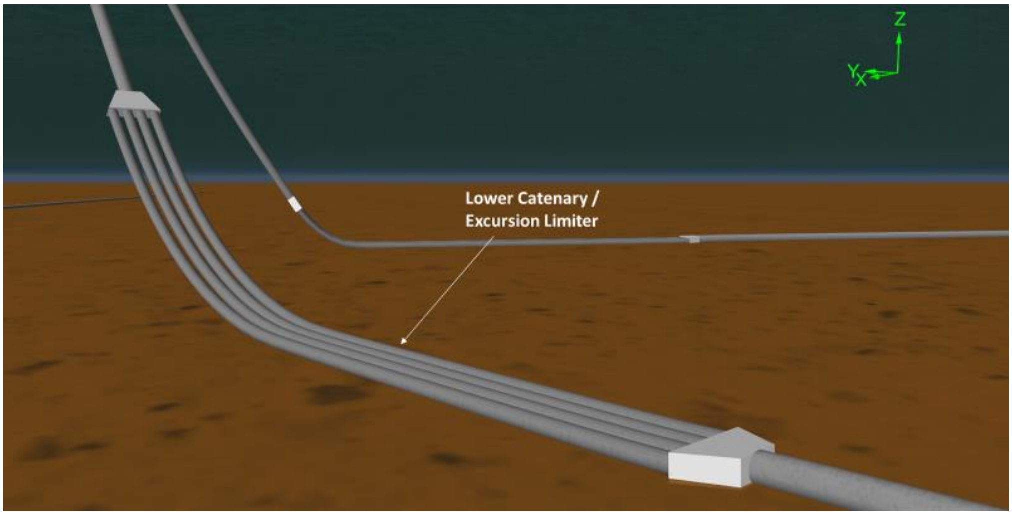


Figure 9-17 – Orcaflex Model Detail of excursion limiter

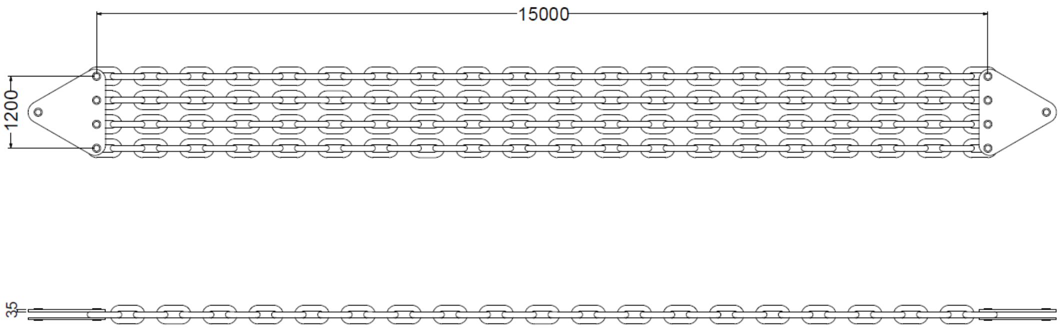


Figure 9-18 – Drawing of proposed excursion limiter

9.6.5 GROUND CHAIN

Continuing from the exit tri-plate of the excursion limiter is ground chain.

- This ground chain provides weight to assist in the anchoring solution and a robust interface with the seabed, and to provide additional weight to reduce clump size.
- This is specified as around 225m of 76mm R3 grade offshore mooring chain with an MBL in excess of 500t.

9.6.6 CHAIN CLUMPS

The device is connected to the seabed using four set of chain clump weights. An example of which is shown in Figure 9-19.

Figure 9-19 – Clump Weight

The seabed in the main berths in the Fall of Warness is predominantly made up of small boulders and rock, a good surface for a chain clump to mould itself into the seabed.

Therefore, the holding capability compared to an equivalent submerged concrete or steel mass will be greater because of the seabed contact.

- OS-E301 Section 2 Part B104 Recommends a coefficient of friction of 1.0 for chain to seabed contact. However, this assumes that the chain length is fully in contact with the seabed.
- BS6349, Part 6, Table 6 recommends a coefficient of friction for deadweight anchors (i.e. a concrete or steel clump) of 0.3 for silt and soft clay to 0.5 for sand and firm clay.
- Barge Mooring" Oilfield, Seamanship, Vol. 6, Hancox recommends a coefficient of friction for chain on rock as 0.8, but possibly the assumption must be that this assumes a length of chain on the seabed.
- Informal tests in the Fall of Warness at EMEC using almost identical clump weight types have proven a coefficient in excess of 0.8 based on load tested anchor pull tests (Ref: AHH Operations, Fall of Warness, June 2012)

With the above in mind, and assuming that almost half of the clump will be in contact with the seabed, a coefficient of 0.6 may be forced because it is the most conservative value and therefore the easiest to force without question or challenge using engineering or operational experiences.

However, to optimise the project financially and operationally an accurate value of drag coefficient has been developed via drag tests on site as reported in LSK-ENG-MEMO-180117, presented in Appendix I. These drag tests have experimentally asserted a coefficient as high as 0.85. On the basis of this a value of 0.80 has been used for this analysis.

9.7 CERTIFICATION & INSPECTION

There will be a mixture of second hand and new components, with certification provided where possible.

All mooring components go through an inspection process by Leask Marine and witnessed as applicable by a reputable survey firm, for example ChainCo.

9.8 MOORING COMPONENTS – ENGINEERING PROPERTIES

The engineering properties used within Orcaflex of the mooring components it presented below.

The make-up of the mooring components are not defined, this relates to the length and size of chain or rope. However, the assumptions associated with the chosen chain/rope type are given in Table 9-5, defined as per BV standard (pg 27 493-NR2015).

	D_{eff}	CD_N **(1) (2)**	CA_N **(1)**	CA_L **(1)**	m_{Ni} **(3)**
Chain	1,8 d	0,8	1,0	0,50	1,13 m_i
Wire rope	D	0,7	1,0	0	1,20 m_i
Fibre rope **(4)**			1,1	0,15	2,00 m_i

(1) Suffix N is for normal (transverse) direction. Suffix L is for longitudinal (tangential) direction.
(2) CD_N are specified as lower bound, to avoid unconservative over-estimate of damping effects.
(3) m_i is the mass per unit length, in air, of the line segment i.
(4) For fibre rope, CA_N and CA_L are inclusive of entrapped water.

Table 9-5 – Mooring Element properties and assumptions

Chain Type	Subset	Mass (t/m)	Axial Stiffness (kn)	CD Normal	CD Axial	Drag Ø Normal (m)	Drag Ø Axial (m)	CA Normal	CA Axial	Contact Ø (m)
107MM STUDLINK[1]	Touchdown	0.2507	1.16E+06	2.6	1.4	0.107	0.0341	1	1	0.3852
76mm STUDLINK	Ground	0.1265	5.83E+05	2.6	1.4	0.076	0.0242	1	1	0.2736

Table 9-6 – Mooring component properties used in Orcaflex

10. ENVIRONMENTAL DATA

This section describes the environmental conditions that the device will be subject to. This data has been supplied by EMEC for the location specified in

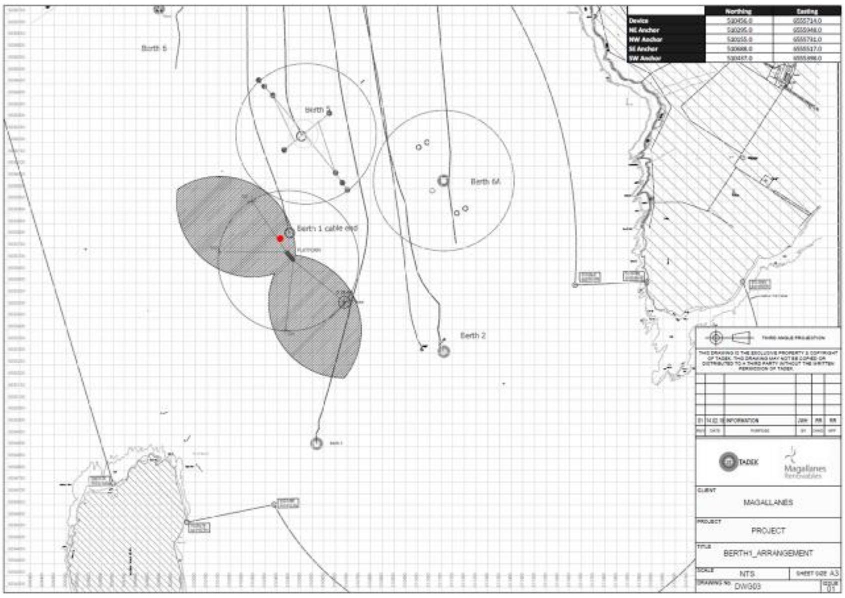


Figure 10-1 - Magallanes Berth with Red dot indicating location of environmental data

It is important to note in this section that the directions of winds, waves and currents are all defined as the direction that they are going towards. This definition is the opposite to the usual conventions for wind and wave directions, as that which they are "coming-from". However, the definition is made for consistency with the current convention, which are usually defined as the direction that the current is flowing towards.

10.1 WATER DEPTH

The water depth at the location of the device is 49m LAT. This is subject to tidal range as below.

Water Level	Depth (m)
HAT	52
MSL	50.5
LAT	49

Table 10-1 Tidal Range

10.2 MARINE GROWTH

Marine growth shall be considered by increasing the outer diameter of the affected member for the calculation of hydrodynamic loads. Marine growth is included within the design as specified in Table 10-2.

Depth below MSL [m]	Marine Growth Thickness [mm]
+2.0m to LAT -10m	150
LAT -10m to seabed	100

Table 10-2 Marine Growth

The density of the marine growth shall be taken to be 1400 kg/m3.

10.3 SEA AND AIR DENSITY

The sea water density is taken as 1026 kg/m^3

The air density is taken as 1.226kg/m^3

10.4 TEMPERATURE, SNOW & ICE

The working temperature are not considered in the analysis, in addition, effects of snow and ice loading are expected to be minimal and are ignored.

10.5 CURRENT

Current speed is plotted against current direction in Figure 10-2 to Figure 10-5. Note current direction is defined as the direction the current is heading towards. It is clear that for current speeds greater than 1m/s, there is only a small variation in the current direction for a given velocity and the currents can be treated as effectively bi-directional.

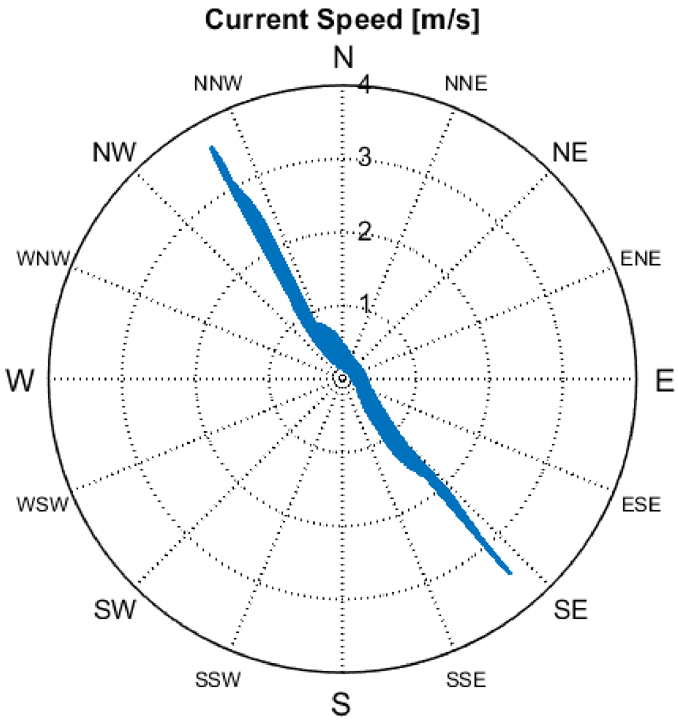


Figure 10-2. Current speed (direction TO) for each direction.

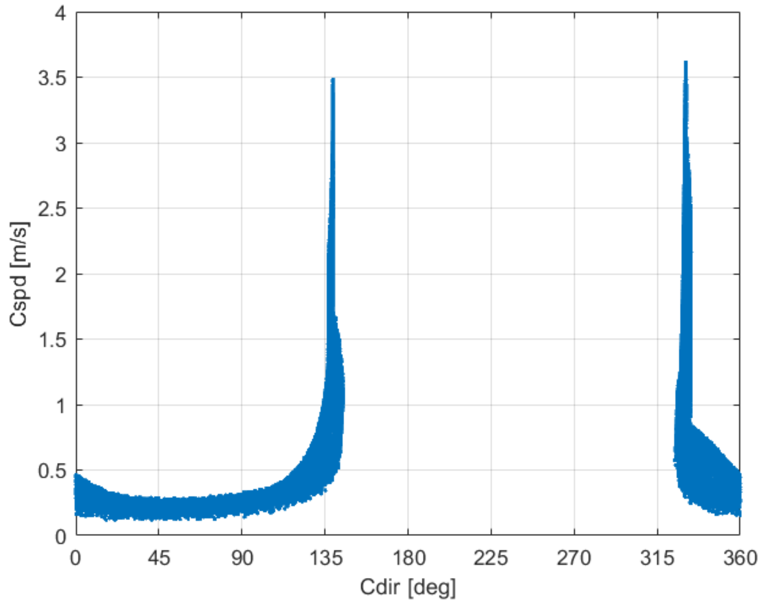


Figure 10-3. Current speed (direction TO) for each direction.

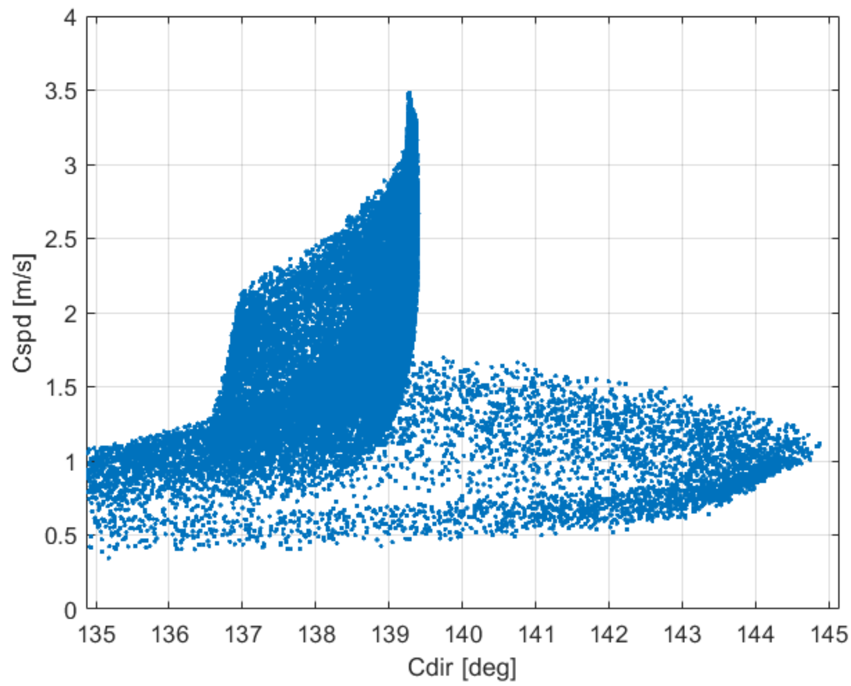


Figure 10-4. FLOOD - Current speed (direction TO) for each direction (zoom for flood).

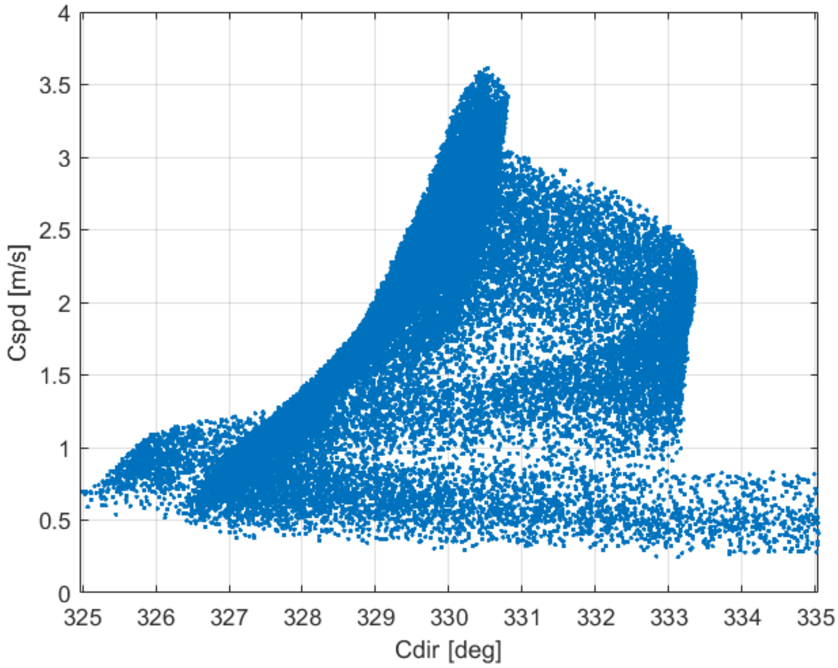


Figure 10-5. EBB - Current speed (direction TO) for each direction (zoom for ebb).

10.6 WAVES

Figure 10-6 shows a scatter plot of H_s against $MDIR$ and Figure 10-7 shows a wave rose, indicating the percentage occurrence in 10° sectors. Note in the figures below the directions of wave is defined as the direction that they are going towards which is against normal convention, however this definition is used for current and so therefore this convention is used for simplicity. The peak wave heights are aligned with the current directions, but there are some medium size sea states in the sector from 0-135°. In the analysis JONSWAP spectra waves will be uses with a γ of 3.3.

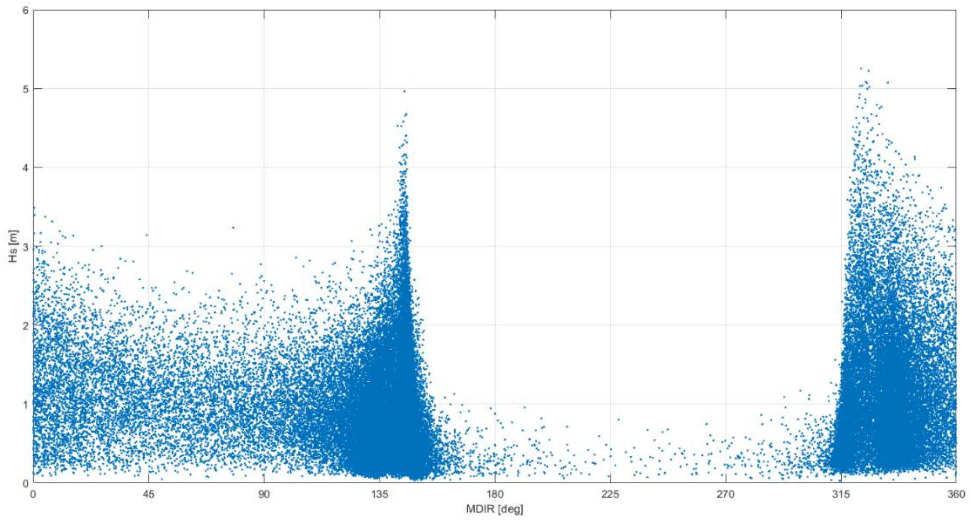


Figure 10-6. Significant wave height against mean wave direction (TO).

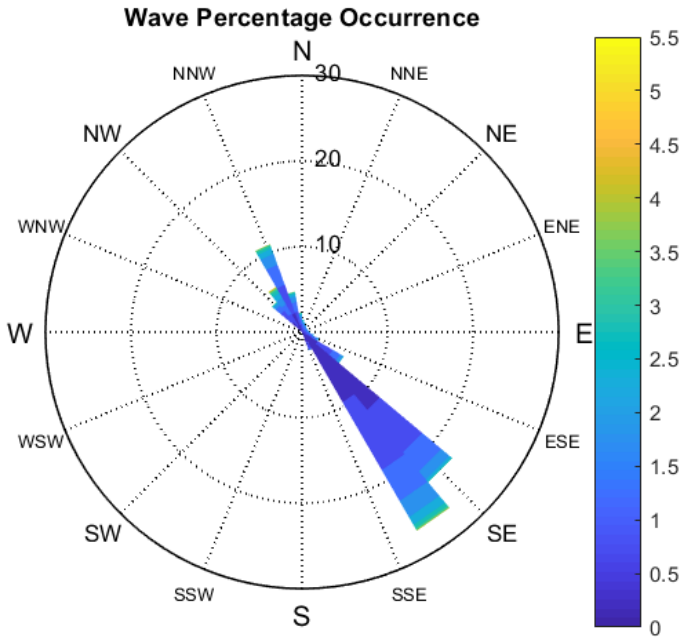


Figure 10-7. Percentage occurrence of sea states binned by mean wave direction (TO). Colour scale denotes significant wave height [m].

10.7 WIND

Figure 10-8 shows wind speed against direction and Figure 10-9 shows a wind rose. Note in the figures below the directions of wind is defined as the direction that they are going towards which is against normal convention, however this definition is used for current and so therefore this convention is used for simplicity.

There is less directional dependence in the wind conditions than the wave conditions, with extreme conditions exceeding 20m/s occurring for a wide range of directions.

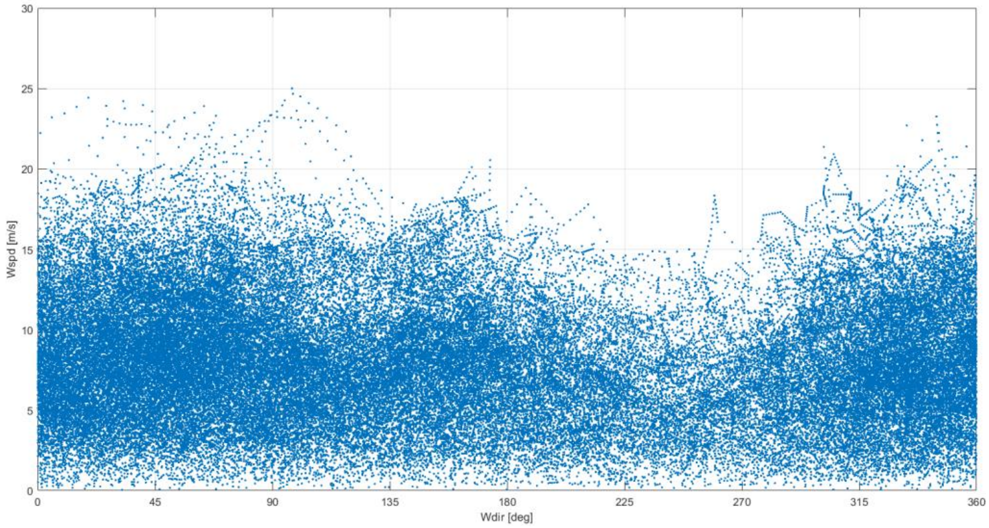


Figure 10-8 - Wind speed against direction. (Note direction is direction wind is heading towards)

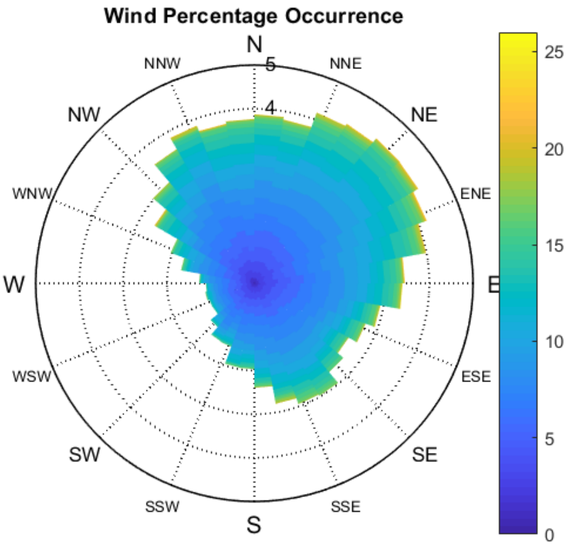


Figure 10-9 - . Percentage occurrence of wind directions. Colour scale denotes wind speed [m/s].

(Note direction is direction wind is heading towards)

10.8 JOINT DISTRIBUTION OF WAVES, WINDS AND CURRENTS

The joint distribution of the Metocean parameters has been assessed for 12 directional sectors of wave conditions. The 12 sectors of 30° width start centred at 0° (due North). For each sector the wave conditions are analysed based on current speed. The current speed is defined as positive in the flood direction (defined here as the 180° sector $45° < Cdir \leq 225°$). Note that the definitions of positive and negative do not indicate the current direction relative to the wave, it is simply a notational convention to simplify the visualisation of the results. Wave sectors between 180° and 300° have been neglected from the analysis because the maximum Hs is much lower in these sectors than in other sectors as seen in Figure 10-6 (less than 2m) and therefore is not expected to lead to design driving load cases.

The significant wave height is expected to vary with current speed. An overview of wave-current interaction effects is presented in [14]. When the current is in the same direction as the waves, the current causes the wavelength to increase and the wave height to decrease. When the current is in the opposite direction to the waves, the wavelength is decreased, and the wave height is increased. The wave-current interact effects are expected to be strongest for the wave sectors that are aligned with the dominant current directions. This is indeed what is observed. Plots of Hs against current speed for each wave sector are shown in 14.

Figure A-6 shows the relation between Hs and current speed for waves in the sector centred at 150°, which shows the largest Hs occurs for small opposing currents (negative current values correspond to ebb tides, with currents toward NNW). As the magnitude of the opposing current increases (larger negative values), the Hs decreases. This is likely to be caused by the large current speeds blocking the waves from propagating and causing wave breaking, leading to a decrease in Hs. For the positive current speeds (in the direction of wave propagation), the Hs decreases with current speed, as would be expected from wave-current interaction theory.

For the wave sector centred at 330° (see Figure A-7), a similar effect is observed. In this case positive (flood) currents are opposed to the wave direction and negative (ebb) currents are with the wave direction. As with the 150° sector, the wave height is increased for opposing currents. However, the Hs does not decrease as quickly with the opposing currents as for the 150° wave sector. The different behaviour is related to the difference in the distribution of wave periods for each sector (see Figures A-28 and A-29 which show the joint distribution of Hs and Tp for the 150° and 330° sectors, binned by current speed – the plots for zero current speed show very different distributions for the two wave direction sectors). The magnitude of the wave-current interaction is governed by the ratio between the current velocity and the wave phase velocity [14]. Therefore, currents have a greater effect on shorter wave periods, which have lower phase velocities than long period waves.

The DNV GL Tidal Turbine standard [15] provides some combinations of return periods of waves, winds and currents to be used for ULS load cases when there is no data available to calculate the joint distribution of these variables. The standard does not provide guidance on how to calculate the joint distribution of Hs, current speed and wave direction when data is available. The DNV GL Position Mooring Standard [13] and Recommended Practice on Environmental Conditions and Environmental Loads [6], both recommend that return periods of Hs are calculated, binned by wave direction sector. For this analysis, due to the strong wave-current interaction effects, the return periods of Hs have been calculated, binned by both wave direction and current speed. This additional binning allows the dependence of Hs on both wave direction and current speed to be assessed.

A current speed bin width of 1m/s has been used for the analysis, with bins centred at integer values of current speed. For each bin, a Weibull distribution is fitted to values of Hs greater than the 90th percentile in the bin, as recommended in [6]. The fit of the Weibull distribution to the data in each bin is shown in 0. Generally, the fit to the data is very good, with the scatter in the observations consistent with that expected from sampling effects (i.e. random variability).

The fitted Weibull distribution has been used to calculate return values of Hs in the bin for return periods of 1, 10, 20 and 50 years. Plots of the return values of Hs as a function of current speed and wave direction are shown in 14. For the definition of load cases, the largest current speed in the bin is associated with the 10-year return-value of Hs (i.e. for the bin with $1.5 < Cspd \leq 2.5$, a current value of 2.5m/s is used for the load case). This definition of the load cases is conservative, since it assumes the largest current in the bin is associated with the return value of Hs. For the current bins centred at -3m/s, the maximum ebb current speed of -3.61m/s was used in place of the bin upper limit of -3.5m/s for this bin. This substitution was made as there was insufficient data to establish a bin for current speeds <-3.5m/s. The substitution will lead to conservative load cases, as it associates a higher current speed with the return values of Hs in the -3m/s bin.

To establish the wind speed to use for each load case, a linear relationship has been established between the windspeed and Hs for each wave direction bin – see 0. This linear relationship is used to define the expected value of wind speed associated with a value of Hs and wave direction. The relationship between windspeed and Hs is assumed to be independent of current speed. It was found that there is a correspondence between the directions of the peak wind speeds and the wave direction. In the definition of the load cases it will be assumed that the wind and wave directions are equal. This is likely to be a conservative assumption as it will lead to larger combined wind and wave loading.

The values of Tp used in each load case are established as follows. For each wave direction and current speed bin, a scatter plot of Hs against Tp has been produced – see 0. The values of Tp associated with the return values of Hs in that bin are calculated as the mean, minimum and maximum of the observed values for Hs above the 90% quantile in the bin. This leads to a conservative range for Tp, as the range of values of Tp observed will narrow with increasing Hs.

10.8.1 OPERATIONAL CONDITIONS

To inform the choice of operational conditions, the non-exceedance values of Hs and wind speed are shown in Figure 10-10 and Figure 10-11. Table 10-3 lists the percentage of the time that the data are below combinations of the 70th, 80th and 90th percentiles of each distribution.

An operational non-exceedance of 90% is chosen for both wind and wave. From the figures and tables below, this is 13.4 m/s (wind) and 1.8 m Hs (wave).

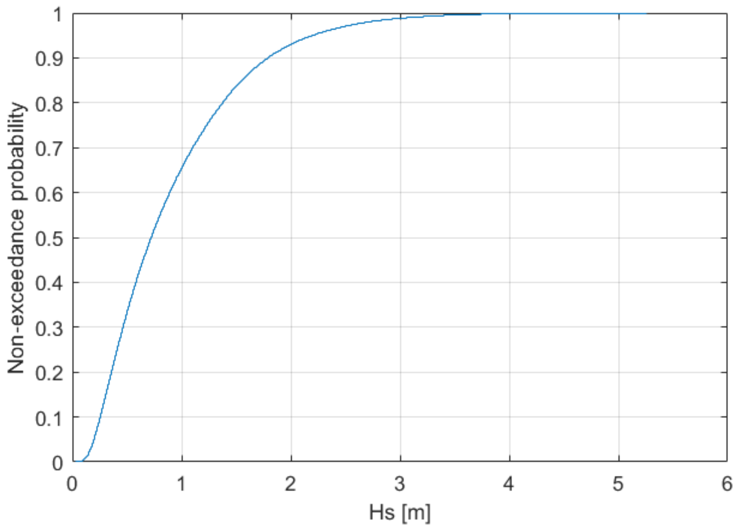


Figure 10-10. Non-exceedance probabilities for Hs.

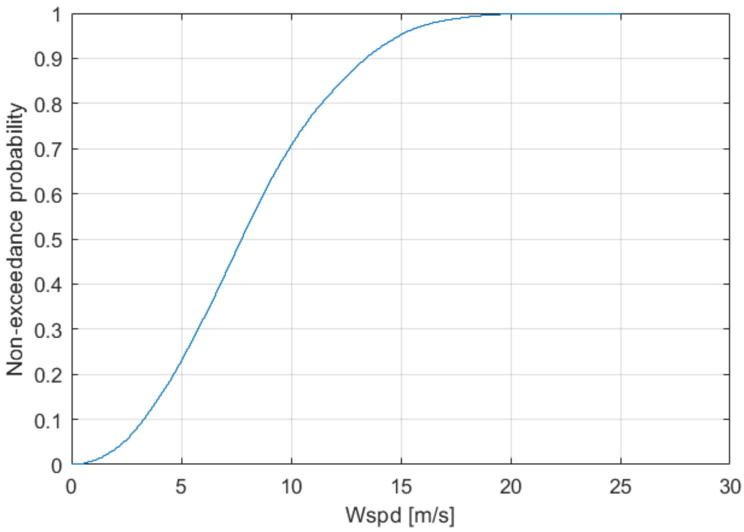


Figure 10-11.Non-exceedance probabilities for wind speed.

Wspd [m/s]	Hs [m]	1.10	1.38	1.79
	Percentile	70	80	90
9.9	70	62.4	66.2	68.6
11.4	80	67.6	73.8	77.6
13.4	90	69.6	78.8	85.5

Table 10-3 Percentage of time that both Hs and wind speed are below 70th, 80th, and 90th percentiles of the distribution.

11. OPERATING & RISK MITIGATION

11.1 NORMAL OPERATING

The operational model of the device can be split into three modes. These modes are described as:

- **Ramp up (0-1m/s) –**As the current ramps up, the blades (which are pitched to induce the maximum lift force at the 1 m/s velocity) will start to rotate. (Note – both sets of blades will start to turn, but in opposite directions to one another). Current drag force, along with drag forces from the device, will exert loads on the mooring system causing an excursion from the natural position and for the device to trim by the bow. A ballasting arrangement is devised to pump water and re-level the platform as the blades are optimised when the tidal flow is perpendicular to the blades.

- **Constant pitch (1-2.5m/s)** - As the current further increases to 2.5 m/s – the blades rotate faster and the drag force increases, leading to the maximum design load and excursion (from current loading only).

- **Variable pitch (Above 2.5 m/s)** – Above 2.5m/s the blades start to pitch and shed load and maintain a constant rotational velocity. In this case as the blades pitch (which is the predominant drag load), the overall drag load decreases and hence the load on the mooring decreases as does the excursion.

11.2 RISK MITIGATIONS

Anything that causes the device to deviate from normal operating either has a mitigation measure to keep it within the normal operating boundaries or becomes an Ultimate Limit State condition or Accidental Limit State. The reason for the deviation can be:

- Environmental conditions exceeded – Above Hs 1.8m the device will cease operating. Average 10-minute mean wind speed in excess of 20m/s.
- Failure of
  - Platform / structural
  - Mooring system
  - Power and or communication to the device
  - Turbine / Generator Failure
  - Control or Electrical system

It is not the aim of this section to discuss **what** would cause the failure (submerged body/vessel impact, fire), but what the mitigating action would be. In almost all cases there is a mitigating measure if any of these occur during normal operation. However, the first issue is normally detecting an incident. Below are the main severe issues and how the platform will respond.

11.3 MONITORING EQUIPMENT

In practical terms there is a range of sensors which will be constantly fed to the Magallanes Turbined team.

System	Description
General position system (GPS)	It records time and date continuously, provides the exact position of the platform at all times and transmits the information to shore. The platform is expected to move on the sea surface within an area previously assigned (based on ebb and flow, depth, length of mooring lines, etc.). In the event that the platform is not held in place, but out of the pre-established range, this may mean that there has been a failure in one of the mooring lines. In such case, GPS will warn without delay about the abnormal position of the platform. This will help to provide a rapid response (with vessels, dive team, etc.) so as to return the platform to a safe and agreed location.
Automatic Identification System (AIS)	AIS is an automatic tracking system used on ships and by vessel traffic services (VTS). Information provided by AIS equipment, such as unique identification, position, course, and speed, can be displayed on a screen. AIS is intended to assist a vessel's watchstanding officers and allow maritime authorities to track and monitor vessel movements and help other vessels to avoid collisions.
Inertial measurement unit (IMU)	Used for monitoring platform stability in terms of pitch, roll and yaw degrees.
Weather station	It records outside temperature, atmospheric pressure, wind speed and wind direction, among others. It helps to anticipate rough weather conditions that may impact on platform behaviour.
Insulation monitoring device	Employed in order to monitor the insulation resistance of unearthed main circuits and to detect early deterioration in the insulation.
Current meter	Instrument for providing with relative water velocity data and measurement of local flow conditions in real time.
Load cells	Four load cells will be installed at the end of each mooring line. That will allow us to measure the loads in each mooring line. This information will be collected by the central PC and monitored alive by the HMI.
Specific monitoring systems	
Variable pitch system	It allows the blades configuration and pitch to change according to the current.

Shaft positioning system	It assures the proper orientation of the rotor blade shaft, so that loads are balanced. It is also intended for facilitating blade assembly and disassembly.
Emergency response systems	
Fire detection system	Set of devices aimed at detecting fire or smoke in the platform and raising the alarm so as to respond as soon as possible and minimize the damages caused.
Bilge pumping system	Provided that unwanted water is present in the platform, and in order to prevent flooding of it, the system is arranged to drain any watertight compartment.

Apart from the aforementioned monitoring and response systems, other variables such as temperature, humidity, pressure, voltage, power, etc. will be monitored within the platform, too. Furthermore, the main components such as generators, converters and gearboxes, among others, will also be monitored in order to ensure they work suitably.

Owing to the nature of the platform, which is conceived for minimising required human intervention, a remotely operated control system is developed in order to display and store within the platform the most relevant parameters. Communication with the platform is established through the umbilical cable and EMEC's subsea cable. Nevertheless, in the event of loss of communication, a satellite or radio communication system, which will behave as a redundant system until required, can be utilised. Both communication systems allow the transmission and operation of the control system variables remotely.

11.3.1 ENVIRONMENTAL CONDITIONS

The wind speed will be constantly monitored on the device. If the mean 10-minute wind speed exceeds 17.5m/s the turbines will be braked.

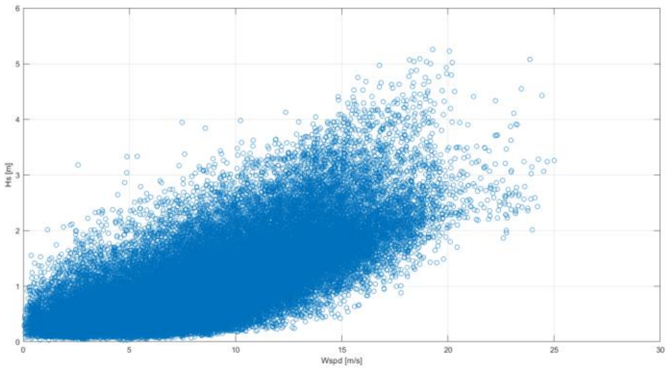


Figure 11-1 - Hs versus Wind speed through the full ten-year time history of data provided by EMC for the site, showing that above 17.5m/s the Hs is approximately always above Hs1m

Of course, it is clear that the wind speed limit of 17.5m/s does not mean that the wave height of Hs 1.8m will never be exceeded.

In order to shut the platform down at a wave limit of Hs 1.8m, there will not be a specific wave rider buoy on the site and therefore specifying a turbine shut down at Hs 1.8m exactly is not practical. Therefore, the motions (Displacement, Acceleration and Velocity) will be monitored and if they are excessive due to environmental conditions then the device will be shut down to reduce loads. The actual

11.3.2 PLATFORM / STRUCTURAL

If there is a platform / structural failure – then this might cause the platform to heel, pitch or behave in an uncharacteristic manner. In extremes the device may lose buoyancy and pick up more drag loads. This will be detected by inclinometers and GPS sensors. The device will then shut down in a controlled manner to reduce loads in the system.

The ballasting system of the device, automatically powered by the on-board diesel generator, will pump water as required to modify trim of the device.

11.3.3 MOORING

The loads in the mooring lines will be constantly monitored using a 250t Crosby SHK-B Bow safety shackle. If the loads are above expected values or above 80% of the design capacity, the platform will be shut down.

If there is a mooring failure this would result in a significant change in platform position. This will be detected by GPS resulting in the turbines being braked. It is not possible that one mooring failure could cause others to fail as the mooring system component capacity has been designed for ALS conditions.

However, excessive excursion may result damage to both the Magallanes dynamic cable and the EMEC cable. The EMEC and the proposed dynamic cable have large MBLs of

850kN and 150kN respectively. Therefore, the excursion is likely to cause significant damage before the cable breaks. To remedy this problem a weak link will be fitted to the cable in the case a failure results in an excessive excursion, the connection between the dynamical cable the EMEC cable will break.

A proposed method of installing a weak line is to cut part of the armour of the dynamic cable in the section between the Splice and the Weighted Touch-Down Clamp. This is shown schematically in Figure 13-1.

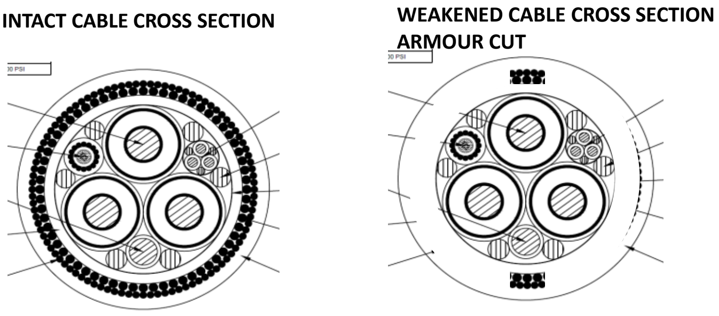


Figure 11-2 - Possible schematic of a weak link arrangement

There is certainty that the weak link in the cable will break because it is combined with a clump weight on the EMEC Splice and also a Weighted Touch-Down Clamp. Therefore, in case of failure, the clump weight will protect the Splice. During operation the Weighted Touch-Down Clamp will protect the cable keeping it in position.

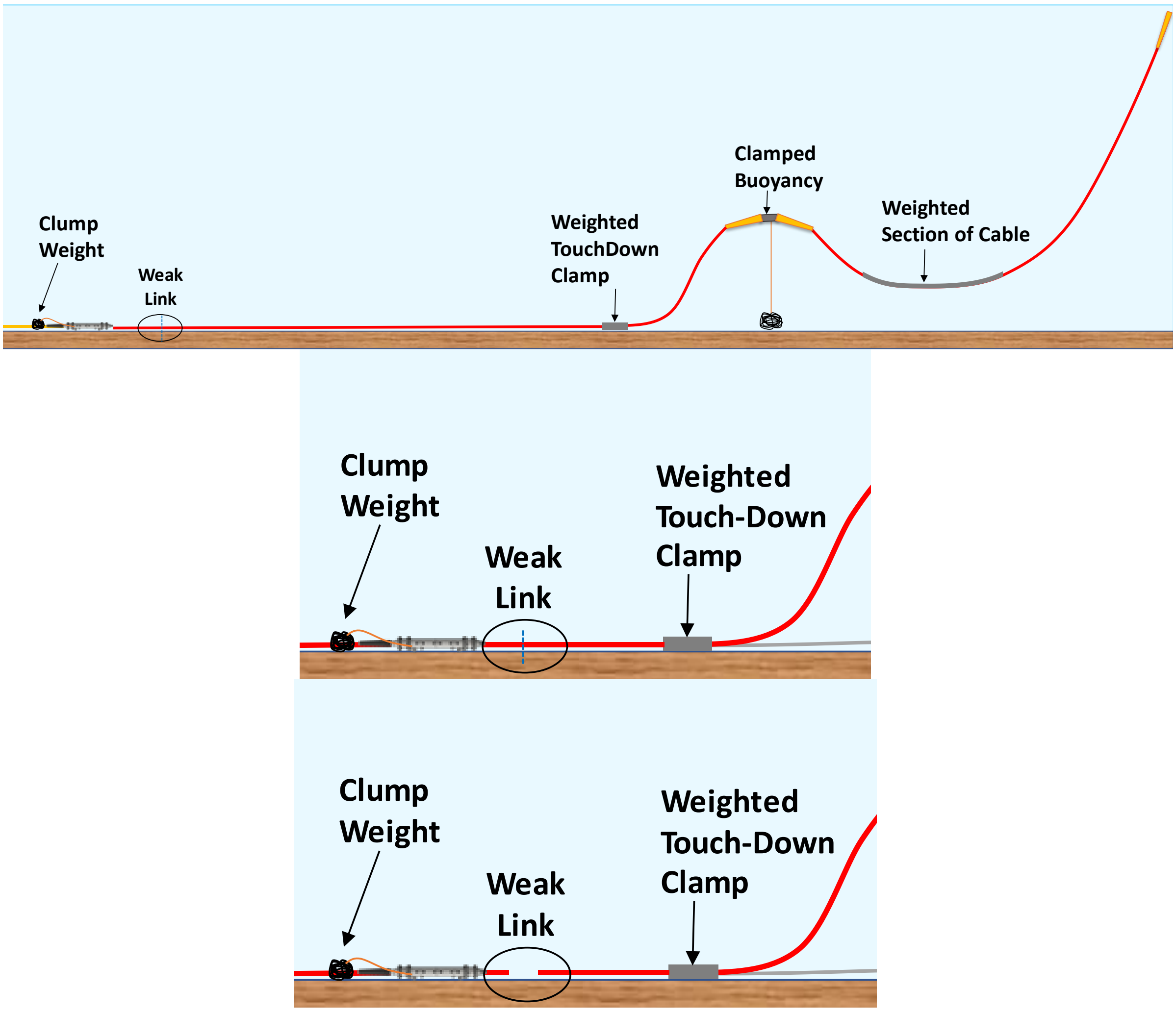


Figure 11-3 – Weak Link to preserve EMEC Cable from damages

TYPE: SHK-B

SHK-B Bow Type Crosby™ Cabled Load Shackle

Features

- Ranges from 1 tonne to 1000 tonne
- High tensile stainless steel construction (to 6.5te) and high tensile carbon steel construction (9.5te and above)
- Environmentally sealed to IP67
- Simple installation and operation
- Shackle and load pin fully certified
- Optional load centralisng bobbin
- Can be supplied with amplified output
- Submersible and many other options available

Typical Applications

- Under-hook hoist/crane weighing
- Cable tension monitoring
- Towing/mooring Tension
- Crane safe load monitoring
- Bollard testing

LCM Systems Ltd
Unit 15, Newport Business Park
Barry Way, Newport
Isle of Wight PO30 5GY UK
Tel: +44 (0) 1983 249264
Fax: +44 (0) 1983 249266
sales@lcmsystems.com
www.lcmsystems.com

Description

The LCM range of SHK-B load shackles are designed for lifting and weighing in rugged or harsh environments, including submersible applications. The shackle pins are forged from high tensile stainless steel to 6.5te and high tensile carbon steel from 9.5te, and are machined to an exacting specification. The basic shackle uses the Crosby G2130 (1 to 25te), G2140 (40 to 120te) and GN Rope H10 (150 to 1000te).

This range of loads cells is proof loaded to 150% of the normal rated load, and is available in a range from 1 tonne to 1000 tonne. The integral cable is normally protected by the anti-rotation bracket or by a seperate protective plate. The SHK-B is internally gauged and the whole instrumented area is sealed to IP67 to protect it in service.

They are simple to install and are available in standard shackle sizes. As an option, a rotating bobbin can be supplied to centralise the load and to minimise any point-load effects when the shackle is placed under load. We are also always happy to discuss any special requirements that can be accommodated.

The SHK-B series can be supplied on its own or combined with our extensive range of instrumentation to provide a complete load monitoring package. A wireless version is also available (see TELSHACK-B data sheet for details).

Specification

Rated load (tonnes)	1, 2, 3.25, 4.75, 6.5, 9.5, 12, 17, 25, 40, 55, 85, 120, 150 200, 250, 300, 400, 500, 600, 700, 800, 900, 1000	
Proof load	150% of rated load	
Ultimate breaking load	300% of rated load	
Output	Between 1.8mV and 3.6mV	
Non-linearity	<±1% of rated load (typically)	
Non-repeatablity	<±0.1% of rated load	
Excitation voltage	10vdc recommended, 15vdc maximum	
Bridge resistance	350Ω	
Insulation resistance	>500MΩ @ 500vdc	
Operating temperature range	-20 to +70˚C	
Compensated temperature range	-10 to +50˚C	
Zero temperature coefficient	<±0.01% of rated load/˚C	
Span temperature coefficient	<±0.01% of rated load/˚C	
Environmental protection level	IP67	
Connection type	10 metre 4 core screened PUR cable (glanded exit)	
Wiring connections	+ve supply: Red +ve signal: Green	-ve supply: Blue -ve signal: Yellow

Available Options

- Special ranges and capacities up to 2000te
- Special electrical connections
- Integral signal conditioning
- Centralising load bobbin
- Subsea, offshore and ROV friendly versions
- Lloyds, ABS, DNV or other third party witnessing
- TEDS option (when used with TR150 handheld display)
- ATEX version available (see SHK-A datasheet) Ex
- Wireless version available (see TELSHACK-B datasheet)
- 3.2 Material Certification

LCM SYSTEMS
Solutions in Load Cell Technology

Figure 11-4 - 250t Load Shackle to be installed at both bow and stern of the platform

11.3.4 POWER OR COMMUNICATION FAILURE

If there is a power or communication failure, the default mitigation is to shut down the device. The system is set up such that the device always needs electrical power (and coms) to be operating otherwise actuators are activated to feather the blades and apply the brakes to stop the turbine. The device can only start back up once power and communications have been re-established, (see section below)

11.3.5 TURBINE / GENERATOR FAILURE

If the part of turbine failed (i.e. blade failure, bearing, gearbox, any part of the power train, generator) then this would be detected. It maybe that there is degradation in expected performance, more likely significant vibration would be detected. In order to avoid further damage to the device then the it will shut down and feather the blades and apply the brake as described above.

11.3.6 CONTROL OR ELECTRICAL SYSTEM FAILURE

If there is control or electrical system failure, then depending on the nature and cause of the failure, this maybe initially difficult to detect. However, settings can be set for example to limit the rotational speed of the turbine by pitching the blades. In all cases the worst-case scenario for example a turbine run away situation, the blades can be pitched to feather, and the break applied. The control system should not allow this, but in an emergency the comms (or power) can be cut and the device will shut down as described above.

After any incident, the cause of the fault should be identified, fixed and made sure it cannot re-occur. An inspection of the device should also be carried out before re-commissioning.

11.3.7 DEVICE BALLASTING SYSTEM

The device has the capability to adjust trim to counter the over-turning moment due to the thrust of the blades. In the event of any failure this system will be operated autonomously vie the on-board diesel generator to maintain the platform level. This will prevent any potential for “broaching” or “fish-tailing” due to the centre of drag being forward of amidships.

11.4 BLADE & BRAKE CONTROL SYSTEM

The blades are pitched with a rack and pinion system powered by a hydraulic piston. There is an accumulator that is pre-charged so that it can actuate the piston without grid power.

Braking system: a hydraulic braking system which employs brake callipers. It is a *negative* system, i.e. with loss of power supply, brake callipers close for braking the power train.

11.5 SURVIVAL CONDITION

10-year environmental conditions present severe loads. Compared with, for example API guidelines which accept 5year return conditions for MODUs, this is onerous, especially considering the device is unmanned, only planned to be installed for a year, has significant monitoring on board, and will be inspected thoroughly several times over the course of the installation period.

12. LOAD CASES

The survival load cases are given in Table 12-1 and Table 12-2.

The operational load cases are given in Table 12-3.

CASE NO.	TYPE	DESCRIPTION		CURRENT Spd [m/s]	CURRENT Dir [deg] FROM	WAVES DIR FROM [deg]	WAVES Dir	WAVES Hs [m]	WAVES Tp [s]	WIND Wspd [m/s]	WIND Wdir FROM
1	SURVIVAL	10yr EBB & Associated Hs	Wind & Waves WITH Tide	3.6	150	150	SSE	3.0	9.5	16	150
2									6.0		
3									12.7		
4		10yr Hs & Associated EBB		1.5				3.9	9.1	19	
5									6.9		
6									11.7		
7		NO CURRENT	SLACK WATER	0.0	-			4.5	9.3	21	
8									7.9		
9									10.1		
10		10yr Hs & Associated FLOOD	Wind & Waves AGAINST Tide	2.5	319			6.0	8.1	27	
11									6.8		
12									9.1		
13		10yr FLOOD & Associated Hs		3.5				5.6	8.2	25	
14									7.8		
15									8.8		
16	SURVIVAL	10yr EBB & Associated Hs	Wind & Waves WITH Tide	3.6	150	180	S	2.3	8.3	15	180
17									4.9		
18									10.2		
19		10yr Hs & Associated EBB		1.5				3.1	7.0	19	
20									4.6		
21									9.9		
22		NO CURRENT	SLACK WATER	0.0	-			3.1	6.6	19	
23									4.3		
24									9.9		
25		10yr Hs & Associated FLOOD	Wind & Waves AGAINST Tide	2.5	319			4.1	5.6	24	
26									4.7		
27									8.9		
28		10yr FLOOD & Associated Hs		3.5				3.3	5.5	20	
29									4.1		
30									7.3		
31	SURVIVAL	10yr EBB & Associated Hs	Wind & Waves WITH Tide	3.6	150	210	SSW	2.1	8.6	16	210
32									7.5		
33									9.8		
34		10yr Hs & Associated EBB		1.5				2.6	6.3	19	
35									3.9		
36									13.5		
37		NO CURRENT	SLACK WATER	0.0	-			2.7	7.3	20	
38									4.1		
39									14.9		
40		10yr Hs & Associated FLOOD	Wind & Waves AGAINST Tide	2.5	319			3.4	6.5	23	
41									3.9		
42									14.6		
43		10yr FLOOD & Associated Hs		3.5				2.7	5.1	20	
44									3.6		
45									12.3		

Table 12-1 – Survival Load Cases 1

CASE NO.	TYPE	DESCRIPTION		CURRENT Spd [m/s]	CURRENT Dir [deg] FROM	WAVES DIR FROM [deg]	WAVES Dir	WAVES Hs [m]	WAVES Tp [s]	WIND Wspd [m/s]	WIND Wdir FROM
46	SURVIVAL	10yr EBB & Associated Hs	Wind & Waves WITH Tide	3.6	150	240	WSW	1.6	8.0	14	240
47									6.9		
48									9.3		
49		10yr Hs & Associated EBB		1.5				2.6	6.7	20	
50									4.0		
51									14.4		
52		NO CURRENT	SLACK WATER	0.0	-			2.6	8.5	20	
53									3.8		
54									14.8		
55		10yr FLOOD & Associated Hs	Wind & Waves AGAINST	3.5	319			2.6	9.9	21	
56									3.9		
57									14.9		
58	SURVIVAL	10yr EBB & Associated Hs	Wind & Waves AGAINST Tide	3.6	150	270	W	1.8	8.6	15	270
59									7.6		
60									10.1		
61		10yr Hs & Associated EBB		1.5				2.7	7.4	22	
62									4.0		
63									14.0		
64		NO CURRENT	SLACK WATER	0.0	-			2.6	10.1	21	
65									3.8		
66									16.1		
67		10yr Hs & Associated FLOOD	Wind & Waves WITH Tide	1.5	319			2.8	14.2	23	
68									13.1		
69									14.9		
70		10yr FLOOD & Associated Hs		3.5				2.5	12.2	20	
71									3.9		
72									15.4		
73	SURVIVAL	10yr EBB & Associated Hs	Wind & Waves AGAINST Tide	3.6	150	300	WNW	2.0	8.4	17	300
74									7.3		
75									9.7		
76		10yr Hs & Associated EBB		1.5				3.4	7.1	26	
77									4.0		
78									14.0		
79		NO CURRENT	SLACK WATER	0.0	-			3.4	8.6	26	
80									4.2		
81									14.7		
82		10yr Hs & Associated FLOOD	Wind & Waves WITH Tide	1.5	319			2.7	8.1	21	
83									3.5		
84									14.6		
85		10yr FLOOD & Associated Hs		3.5				2.2	11.0	18	
86									3.5		
87									16.8		
88	SURVIVAL	10yr EBB & Associated Hs	Wind & Waves AGAINST Tide	3.6	150	330	NWN	3.2	7.6	16	330
89									6.5		
90									9.8		
91		10yr Hs & Associated EBB		1.5				5.7	5.8	26	
92									5.3		
93									6.2		
94		NO CURRENT	SLACK WATER	0.0	-			4.7	5.2	22	
95									4.4		
96									5.5		
97		10yr Hs & Associated FLOOD	Wind & Waves WITH Tide	1.5	319			3.0	8.3	15	
98									4.5		
99									15.4		
100		10yr FLOOD & Associated Hs		3.5				2.1	10.5	12	
101									5.1		
102									16.5		

Table 12-2 - Survival Load Cases 2

CASE NO.	TYPE	DESCRIPTION		CURRENT Spd [m/s]	CURRENT Dir [deg] FROM	WAVES DIR FROM [deg]	WAVES Dir	WAVES Hs [m]	WAVES Tp [s]	WIND Wspd [m/s]	WIND Wdir FROM
103	OPERATIONAL	10yr EBB & Associated Hs	Wind & Waves WITH Tide	3.5	150	150	SSE	1.8	5	13	150
104									6		
105									7		
106									8		
107									10		
108									12		
109									14		
110	OPERATIONAL	10yr EBB & Associated Hs	Wind & Waves WITH Tide	3.6	150	180	S	1.8	5	13	180
111									6		
112									7		
113									8		
114									10		
115									12		
116									14		
117	OPERATIONAL	10yr EBB & Associated Hs	Wind & Waves WITH Tide	3.6	150	210	SSW	1.8	5	13	210
118									6		
119									7		
120									8		
121									10		
122									12		
123									14		
124	OPERATIONAL	10yr EBB & Associated Hs	Wind & Waves WITH Tide	3.6	150	240	WSW	1.8	5	13	240
125									6		
126									7		
127									8		
128									10		
129									12		
130									14		
131	OPERATIONAL	10yr FLOOD & Associated Hs	Wind & Waves WITH Tide	3.5	319	270	W	1.8	5	13	270
132									6		
133									7		
134									8		
135									10		
136									12		
137									14		
138	OPERATIONAL	10yr FLOOD & Associated Hs	Wind & Waves WITH Tide	3.5	319	300	WNW	1.8	5	13	300
139									6		
140									7		
141									8		
142									10		
143									12		
144									14		
145	OPERATIONAL	10yr FLOOD & Associated Hs	Wind & Waves WITH Tide	3.5	319	330	NWN	1.8	5	13	330
146									6		
147									7		
148									8		
149									10		
150									12		
151									14		

Table 12-3 - Operational Cases

13. RESULTS

13.1 ULS CASES

The results summary is shown in Table 13-1.

Type	Wave Direction		Current	Factored Loads: Tension at Hull (Te) N_Hull	NW	NE	S_Hull	SE	SW	Tension at Anchor (Te) NW	NE	SE	SW	Max Excursion (m)
Survival	150	SSE	Flood & EBB	109	71	84	232	124	112	72	81	131	109	26
	180	S	Flood & EBB	102	50	84	134	89	60	50	82	91	56	22
	210	SSW	Flood & EBB	108	70	80	131	95	46	63	78	89	49	26
	240	WSW	Flood & EBB	110	68	88	109	78	33	58	91	78	37	23
	270	W	Flood & EBB	106	63	83	103	74	32	56	86	75	38	23
	300	WNW	Flood & EBB	112	70	87	106	75	32	62	89	76	37	24
	330	NWN	Flood & EBB	193	67	135	114	79	36	58	129	80	40	25
Opp	150	SSE	Wind & Waves WITH Tide	16	10	8	158	78	82	13	10	80	85	18
	180	S	Wind & Waves WITH Tide	23	15	10	156	82	80	17	10	84	83	19
	210	SSW	Wind & Waves WITH Tide	29	21	11	154	79	78	21	10	82	83	20
	240	WSW	Wind & Waves WITH Tide	28	20	12	142	77	69	20	10	79	74	19
	270	W	Wind & Waves WITH Tide	152	53	101	16	9	8	50	107	13	10	16
	300	WNW	Wind & Waves WITH Tide	153	53	100	15	8	7	50	105	12	10	16
	330	NWN	Wind & Waves WITH Tide	161	61	100	13	5	9	60	103	11	11	18

Table 13-1 - Result Summary

The full results are shown below

Case Number	Factored Loads: Tension at Hull (Te) N_Hull	NW	NE	S_Hull	SE	SW	Tension at Anchor (Te) NW	NE	SE	SW	Max Excursion (m)
1	39	32	12	217	124	94	29	12	131	95	22
2	47	37	12	109	98	48	33	12	99	48	21
3	39	33	11	135	89	52	28	12	96	54	20
4	36	25	13	162	73	92	27	18	68	87	18
5	37	25	14	232	121	112	28	19	120	109	22
6	33	23	13	126	56	70	25	18	53	67	16
7	39	26	32	136	66	71	28	21	59	64	15
8	57	56	34	164	77	91	29	22	69	84	18
9	41	26	16	123	55	69	29	21	48	62	14
10	75	35	43	124	62	69	38	46	49	56	7
11	78	39	43	159	75	86	43	47	61	70	6
12	74	35	44	93	46	52	38	46	38	45	7
13	109	71	79	95	39	68	72	78	31	46	25
14	102	62	80	88	36	64	64	80	30	43	25
15	102	32	84	76	24	55	36	81	21	37	26

Table 13-2 - Survival Case Wave Direction 150

Case Number	Factored Loads: Tension at Hull (Te)						Factored Loads: Tension at Anchor (Te)				Max Excursion (m)
	N_Hull	NW	NE	S_Hull	SE	SW	NW	NE	SE	SW	
16	42	36	11	132	88	46	30	11	91	48	22
17	43	36	9	123	89	35	31	12	87	38	20
18	44	37	10	129	87	49	30	12	91	51	22
19	61	50	14	134	78	60	44	18	71	56	20
20	57	43	15	80	48	32	41	20	47	35	15
21	50	39	14	105	65	41	37	17	60	42	19
22	63	49	15	127	79	50	45	20	72	46	22
23	52	38	14	69	44	27	39	20	42	31	15
24	50	37	14	81	50	31	37	19	47	34	16
25	87	49	43	104	65	39	50	46	53	34	13
26	77	41	37	67	45	25	42	41	37	24	14
27	79	47	36	61	37	26	49	41	33	26	12
28	102	34	84	39	25	27	38	82	23	21	22
29	91	29	74	30	18	18	34	73	18	18	21
30	101	34	82	36	20	27	38	82	19	21	22

Table 13-3 - Survival Case Wave Direction 180

Case Number	Factored Loads: Tension at Hull (Te)						Factored Loads: Tension at Anchor (Te)				Max Excursion (m)
	N_Hull	NW	NE	S_Hull	SE	SW	NW	NE	SE	SW	
31	58	46	13	124	84	41	36	11	88	44	24
32	55	47	12	128	87	46	36	11	89	49	24
33	57	45	13	113	77	37	36	11	81	41	23
34	78	63	17	131	95	41	52	20	88	41	26
35	52	39	14	65	43	23	38	19	43	28	16
36	45	34	13	63	41	24	33	17	39	28	15
37	91	70	21	91	63	30	63	22	55	32	22
38	69	54	15	79	57	23	51	21	51	26	20
39	47	32	15	48	29	21	33	20	31	25	12
40	108	55	54	69	46	26	54	54	40	25	16
41	56	35	31	42	27	16	38	36	27	19	11
42	77	41	37	40	27	15	42	38	26	18	11
43	100	31	80	31	21	21	36	78	21	19	22
44	83	26	68	26	17	17	32	67	18	16	22
45	93	28	77	27	16	19	32	78	16	17	23

Table 13-4 - Survival Case Wave Direction 210

Case Number	Factored Loads: Tension at Hull (Te)						Factored Loads: Tension at Anchor (Te)				Max Excursion (m)
	N_Hull	NW	NE	S_Hull	SE	SW	NW	NE	SE	SW	
46	42	33	11	107	76	32	30	12	76	37	20
47	46	35	11	109	78	33	30	12	78	37	21
48	43	33	10	105	74	31	29	12	76	36	21
49	84	68	21	102	69	33	58	23	65	36	23
50	67	52	16	65	45	21	47	19	43	26	18
51	44	33	14	56	35	23	32	18	35	27	13
52	73	55	20	71	51	21	50	24	46	24	20
53	51	38	15	55	37	19	38	20	37	25	14
54	46	31	16	42	25	19	32	20	28	23	10
55	110	41	88	25	19	15	44	91	18	15	22
56	83	26	68	27	16	19	32	67	18	17	22
57	99	31	82	25	16	17	34	84	17	16	23

Table 13-5 - Survival Case Wave Direction 240

Case Number	Factored Loads: Tension at Hull (Te) N_Hull	NW	NE	S_Hull	SE	SW	Tension at Anchor (Te) NW	NE	SE	SW	Max Excursion (m)
58	39	30	10	100	72	32	27	12	74	37	19
59	48	35	13	103	74	32	31	14	75	37	20
60	37	29	10	97	70	32	26	11	72	38	19
61	84	63	24	71	51	22	56	26	48	26	20
62	53	38	15	58	39	20	38	20	39	25	15
63	46	32	16	48	29	20	31	19	31	26	11
64	59	39	20	47	31	17	40	24	32	22	13
65	52	37	15	46	31	16	38	21	33	23	13
66	51	33	20	37	20	18	33	23	25	24	7
67	59	38	22	40	27	15	38	27	28	19	11
68	64	41	24	39	25	15	41	27	27	20	12
69	59	37	23	37	23	15	37	27	25	20	10
70	106	30	82	23	13	15	32	84	16	15	22
71	81	24	66	27	11	19	30	64	14	17	22
72	103	26	83	25	14	17	30	86	17	16	23

Table 13-6 - Survival Case Wave Direction 270

Case Number	Factored Loads: Tension at Hull (Te) N_Hull	NW	NE	S_Hull	SE	SW	Tension at Anchor (Te) NW	NE	SE	SW	Max Excursion (m)
73	41	30	12	102	73	32	28	13	74	37	18
74	46	32	13	106	75	32	30	14	76	37	19
75	47	34	13	100	72	31	31	14	72	37	19
76	103	70	37	57	37	21	62	35	39	26	14
77	45	29	16	41	24	18	31	20	29	25	9
78	44	27	19	45	22	23	27	21	28	29	8
79	100	55	45	42	27	18	51	44	29	23	12
80	49	32	19	37	22	16	34	24	27	23	9
81	60	33	28	38	18	22	33	29	23	26	6
82	95	48	49	30	18	15	49	47	23	21	10
83	33	19	15	26	13	14	24	22	19	20	3
84	62	33	30	28	14	15	34	31	19	20	6
85	112	51	87	25	14	17	53	89	16	16	23
86	79	50	29	17	9	10	53	36	14	13	8
87	94	58	75	26	14	18	62	78	16	17	24

Table 13-7 - Survival Case Wave Direction 300

Case Number	Factored Loads: Tension at Hull (Te) N_Hull	NW	NE	S_Hull	SE	SW	Tension at Anchor (Te) NW	NE	SE	SW	Max Excursion (m)
88	64	47	20	110	77	35	38	17	78	39	19
89	64	45	20	114	79	36	37	16	80	38	18
90	49	36	16	105	74	35	32	14	76	40	19
91	147	63	85	47	20	28	56	70	28	33	12
92	145	63	84	51	22	29	55	69	30	33	10
93	138	55	86	46	20	30	48	68	26	34	12
94	181	60	129	43	11	33	50	124	17	33	22
95	86	30	58	37	10	29	30	52	17	31	15
96	193	67	135	43	24	34	52	129	19	34	25
97	174	61	117	15	6	11	54	112	13	16	20
98	94	37	58	12	4	9	38	53	13	15	12
99	101	40	63	16	6	11	38	58	14	16	14
100	146	59	90	13	5	9	58	95	11	11	18
101	134	56	78	12	4	8	57	78	11	11	14
102	130	55	75	16	7	10	56	79	11	12	16

Table 13-8 - Survival Case Wave Direction 330

Case Number	Factored Loads										Max Excursion (m)
	Tension at Hull (Te)						Tension at Anchor (Te)				
	N_Hull	NW	NE	S_Hull	SE	SW	NW	NE	SE	SW	
106	13	10	5	158	78	82	13	10	80	85	18
107	13	9	5	146	75	71	13	9	79	73	17
108	13	9	5	143	75	71	13	10	78	75	18
109	16	8	8	137	73	65	13	10	78	68	17
110	17	10	9	152	82	71	13	10	84	72	16
111	17	10	9	149	80	70	13	10	83	72	17
112	20	12	10	155	81	78	15	9	83	81	19
113	23	15	10	156	78	80	17	10	80	83	19
114	21	13	9	154	78	78	16	10	82	81	19
115	18	10	9	140	76	67	14	9	81	69	18
116	16	9	9	135	73	63	13	9	79	66	17
117	19	11	11	146	79	68	13	10	82	69	17
118	25	15	11	145	77	70	16	9	79	73	18
119	25	16	11	147	78	73	17	9	81	76	18
120	29	21	11	154	79	78	21	9	82	83	20
121	27	19	10	140	73	72	19	10	78	77	19
122	27	21	9	133	71	65	20	9	76	71	20
123	19	13	9	131	71	60	15	9	77	64	18
124	21	11	11	141	76	66	13	9	79	68	16
125	24	14	12	142	77	68	16	10	79	71	17
126	28	20	11	137	72	69	20	10	75	74	19
127	28	18	11	138	72	69	19	10	76	73	18
128	27	19	10	130	69	63	19	9	73	67	18
129	22	13	9	130	70	60	15	9	75	64	18
130	18	11	9	126	69	59	14	9	74	63	17

Table 13-9 - Operational EBB Current

Case Number	Factored Loads										Max Excursion (m)
	Tension at Hull (Te)						Tension at Anchor (Te)				
	N_Hull	NW	NE	S_Hull	SE	SW	NW	NE	SE	SW	
131	130	47	88	14	8	7	46	92	13	10	14
132	137	46	93	15	9	8	45	97	13	10	15
133	148	50	99	16	9	8	47	105	13	10	15
134	152	53	100	15	9	8	50	106	13	10	15
135	152	52	101	15	9	8	49	107	13	10	16
136	137	47	93	15	9	8	46	100	13	10	15
137	127	45	88	14	9	6	46	95	13	10	15
138	129	42	89	11	7	5	44	91	12	10	14
139	139	46	95	14	7	7	44	98	12	10	15
140	153	53	100	14	7	7	50	105	12	10	16
141	147	50	98	14	8	7	48	102	12	10	16
142	146	50	96	13	8	5	49	102	12	10	16
143	138	47	93	15	8	7	45	101	12	10	16
144	134	43	92	15	8	7	44	100	12	10	16
145	124	53	71	11	4	8	54	72	11	11	14
146	133	56	78	13	4	9	56	78	11	11	15
147	145	59	87	13	4	9	59	88	11	11	16
148	161	61	100	13	4	9	60	103	11	11	17
149	140	57	84	13	5	9	57	87	11	11	18
150	135	56	80	13	5	9	56	82	11	11	16
151	126	54	73	13	5	9	56	77	11	11	16

Table 13-10 - Operational Flood Current

13.2 TIME HISPORY OF LOADS

It is proposed that the gravity anchors are not been specified by the project strictly according to DNV-OS-E301. Instead of factored capacity a safety factor of 1 is proposed. This is justified by:

- Total redundancy - linking of in-line or end clump weights instead of sizing anchors for the maximum ALS cases.
- A close monitoring regime of both device excursion using GPS linked to the control system, and design loads monitored by load shackles;
- The potential to modify the system post installation. This will be achieved, either by adding a pair of chain clumps either side of the ground chain prior to the anchor or adding a chain clump to a tail left from the anchor after installation;
- The 0.8 friction coefficient is conservative considering drag trials on site;
- The lack of necessity to achieve DNV class approval of the system;
- Maintaining no/negligible risk to both the project and third-party assets;
- Proving the economic case for a potential industry;

Anchor sizing is also supported by recognising that peaks in anchor tensions are momentary spikes of a few seconds.

A statistical assessment of a 3-hour simulation:

- **Total Duration Over 3 Hrs** – total period during the 3 hours storm when the anchor loads exceeded the maximum anchor utilisation limit
- **No. events** - The number of events
- **Max. Duration One Event** – The duration of event.

Table 2-2 summaries the statistical results highlighting how peak tensions occurred during a few seconds within a 3-hour 10-year storm. Such brief peak loading affects anchor position by a negligible distance and therefore of no consequence to mooring loads within the components which are sized strictly according to DNV-OS-E301, the dynamic cable or third-party assets. Hence it is comfortable that the anchor capacities are suitable.

Event	Max. Duration One Event (s)	No. Event	Total Duration Over 3 Hrs (s)
Peak 1	4.8	23	38
Peak 2	1.9	1	2
Peak 3	4.1	2	6
Peak 4	1.2	1	1
Peak 5	0.5	2	1

Table 13-11 - Time History of Loads in NW line

13.3 ALS CASES

13.3.1 OVERVIEW

ALS cases were run to simulate loads and platform behaviour after a failure event.

Failure cases have been split into low and medium severity and two Consequence Classes have been explored. These are summarised as follows:

- **FAILURE LEVEL 1 – Low Severity, Low Risk**
  - ALS Case 1 - NW Leg fails
  - ALS Case 3 - NE Leg fails
  - ALS Case 5 - SE Leg fails
  - ALS Case 7 - SW Leg fails
- **FAILURE LEVEL 2 – Medium Severity, Very Low Risk**
  - ALS Case 2 - South hull attachment point fails
  - ALS Case 4 – South hull attachment point fails
  - ALS Case 6 - North hull attachment point
  - ALS Case 8 - North hull attachment point

In a failure event, two main consequences have been identified with outcomes which the design needs categorically to avoid else, if this is not possible, to mitigate. These outcomes summarised as follows:

- **CONSEQUENCE CLASS 1 - Large Excursions**
  - Outcome 1 - Damage to EMEC and dynamic cable
  - Outcome 2 – Collision with neighbouring devices e.g. Scotrenewables
- **CONSEQUENCE CLASS 2 – Cascade Effects**
  - Outcome 3 – Extreme motions, loads & further system failures

13.3.2 LOAD CASES

The 10 most extreme Survival cases were selected as the ALS cases. These are summarised in Table 13-12

Type	LC	Wave Direction		Current	Vc (m/s)	Hs(m)
ALS	ALS_1	150	SSE	Wind & Waves WITH Tide	3.6	3.0
	ALS_2	150	SSE	Wind & Waves WITH Tide	3.6	3.0
	ALS_3	240	WSW	Wind & Waves WITH Tide	3.6	1.6
	ALS_4	240	WSW	Wind & Waves WITH Tide	3.6	1.6
	ALS_5	270	W	Wind & Waves WITH Tide	3.5	2.5
	ALS_6	270	W	Wind & Waves WITH Tide	3.5	2.5
	ALS_7	330	NWN	Wind & Waves WITH Tide	3.5	2.1
	ALS_8	330	NWN	Wind & Waves WITH Tide	3.5	2.1

Table 13-12 – ALS Load Cases

13.3.3 FAILURE LEVEL 1 – LOW SEVERITY, LOW RISK

Four models were created to identify how the tidal platform would behave should a single leg fail.

- Model 1 - NW Leg fails
- Model 2 - NE Leg fails
- Model 3 - SE Leg fails
- Model 4 - SW Leg fails

Consequence Class 1 – Excursion

- In some cases, the maximum excursion is not a risk to the cable.
- However, in most cases the maximum excursion increases significantly and will damage the dynamic cable.

Consequence Class 2 – Cascade effects

- The results show that a single leg failure can result in similar or even reduced loads because of the removal of some yaw restraint which helps to decrease loads in some cases.
- As a result, Consequence Class 2 is of little concern from Failure Level 1

13.3.4 FAILURE LEVEL 2 – MEDIUM SEVERITY, VERY LOW RISK

A model was created to identify how the platform would behave should either the North or the South hull attachment points fail.

Consequence Class 1 – Excursion

- In all cases the maximum excursion increases significantly and will damage the dynamic cable.

Consequence Class 2 – Cascade effects

- Loss of either the North of South Hull Attachment point would further remove yaw restrains allowing the device greater freedom to weather vane which can result in a reduction in loads experience in the remaining lines
- As a result, Consequence Class 2 is of little concern from Failure Level 2

13.3.5 STEPS TO MITIGATE OUTCOMES FROM CONSEQUENCE CLASS 1

Consequence Class 1, increased excursions, have two main outcomes:

- Outcome 1 - Damage to EMEC and dynamic cable
- Outcome 2 – Collision with neighbouring devices e.g. Scotrenewables

Mitigation of Outcome 1

Should the device experience an excessive excursion the weak link discussed in Section 11.3.3 and presented in Figure 13-1 is a simple and the principal mitigation.

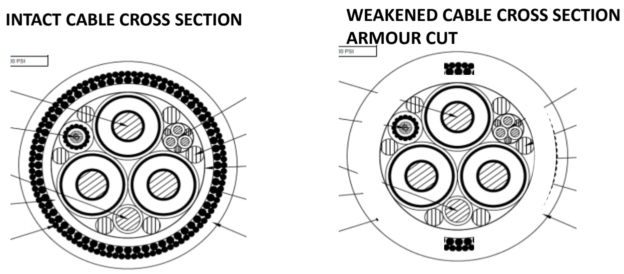
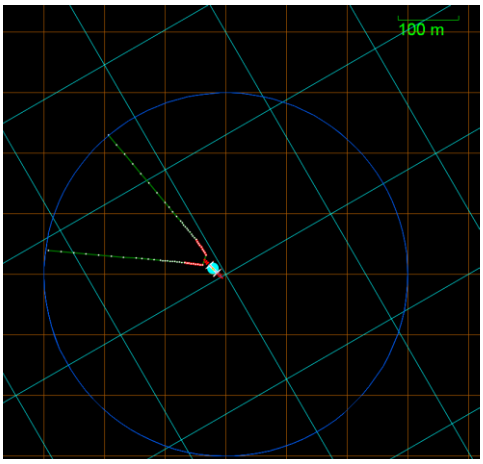


Figure 13-1 - Possible schematic of a weak link arrangement

Mitigation of Outcome 2

To satisfy the second outcome a model simulating the failure of the south hull attachment point was run with the predominate weather conditions coming from the South West. The idea behind this case was to anticipate would the Magallanes tidal platform interfere with the Scotrenewables device in the worst-case scenario. Figure 13-2, Figure 13-3, Figure 13-4 and Figure 13-5 shows the model after several time steps and show of the device pivots around the North West Line.



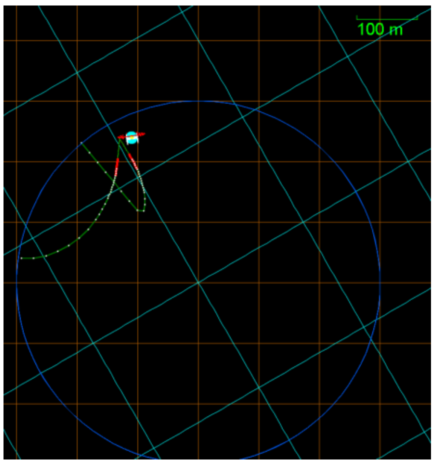
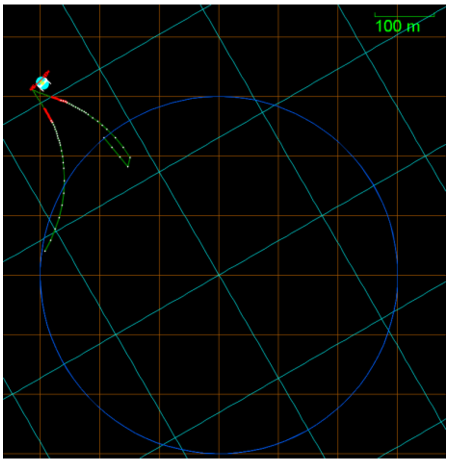


Figure 13-2 – South Hull attachment failure combined with South West weather. 0s

Figure 13-3 – South Hull attachment failure combined with South West weather. 2000s



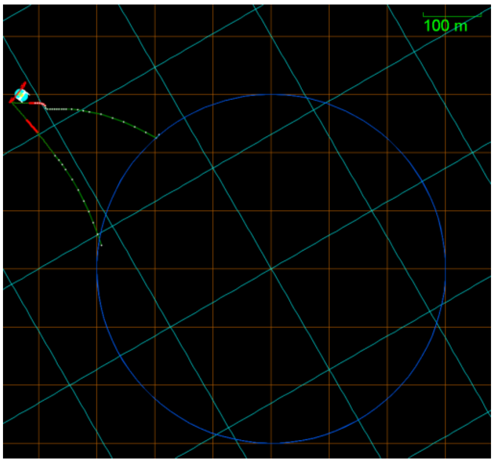


Figure 13-4 – South Hull attachment failure combined with predominate South West. Time 3000s

Figure 13-5 – South Hull attachment failure combined with predominate South West. Time 5000s

From examining the figures, it can be seen that the device pivots around the North West anchor position. To illustrate this in relation to the ScotRenewable Device Figure 13-6 was producing with the 312m diameter circle around the NW line.

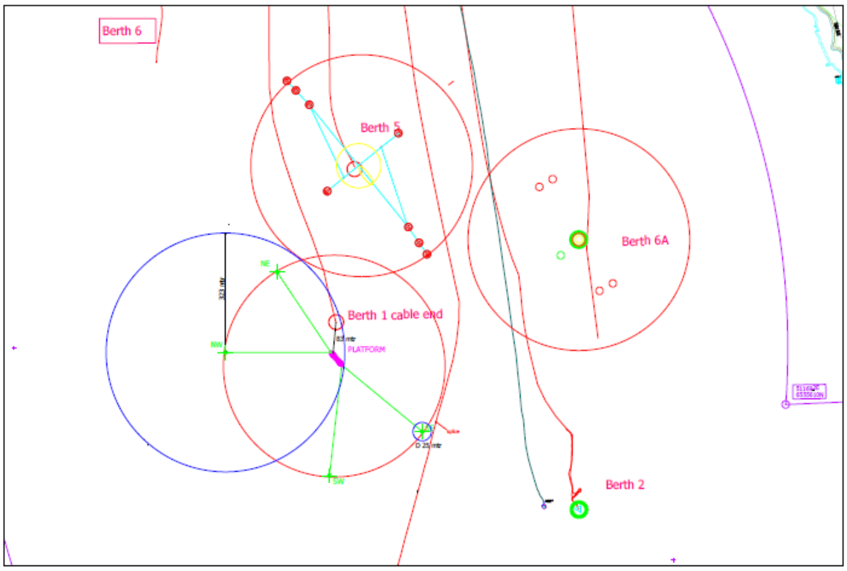


Figure 13-6 - Proposed Position of tidal platform illustrating maximum excursion should south bridal fails

The drawing illustrates how the device is in no danger of colliding the with ScotRenewables device, even with the device positioned in the preferred northly location.

13.3.6 ALS RESULTS

The ALS results are presented in Figure 13-7.

							Factored Loads									
							Tension at Hull (Te)						Tension at Anchor (Te)			
Type	LC	Wave Direction		Current	Vc (m/s)	Hs(m)	N_Hull	NW	NE	S_Hull	SE	SW	NW	NE	SE	SW
ALS	ALS_1	150	SSE	Wind & Waves WITH Tide	3.6	3.0	173	149	24	199		199	149	7		205
	ALS_2	150	SSE	Wind & Waves WITH Tide	3.6	3.0	124	97	39	0			101	28		
	ALS_3	240	WSW	Wind & Waves WITH Tide	3.6	1.6	119	103	16	161		161	96	7		167
	ALS_4	240	WSW	Wind & Waves WITH Tide	3.6	1.6	77	55	29	0			58	16		
	ALS_5	270	W	Wind & Waves WITH Tide	3.5	2.5	126		126	91	76	15		128	65	8
	ALS_6	270	W	Wind & Waves WITH Tide	3.5	2.5	0			84	73	33			72	23
	ALS_7	330	NWN	Wind & Waves WITH Tide	3.5	2.1	131	131		93	17	77	132		8	64
	ALS_8	330	NWN	Wind & Waves WITH Tide	3.5	2.1	0			84	72	38			70	30

Figure 13-7 - ALS Results

14. STRUCTURAL / FEA

14.1 OVERVIEW

To assess the structural integrity of the hull and hull attachment points FEA was performed, using drawings and a 3D model supplied by Seamaster.

The purpose of this work was:

- To verify hull capacity asserted in Reference 19
- To verify and respond to onerous comments by the TPV presented in Reference 20.
- To apply real mooring load vectors to the model

The mesh of the model is shown in Figure 14-1.

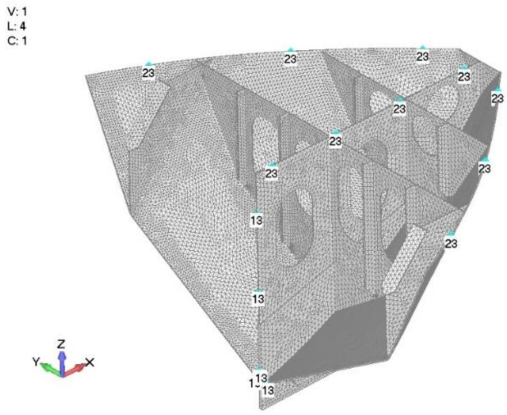


Figure 14-1 - FEA Mesh

14.2 LOAD CASES

14.2.1 OVERVIEW

Initially 6 loads cases were run, as summarised in Table 14-1, varying the load and the angle at which the load was applied.

Load case	Load (te)	Angle relative to Vessel Centreline (deg)	Vertical Angle Relative to keel (deg)
1	250	0	45
2	250	15	45
3	250	30	45
4	175	0	45
5	175	15	45
6	175	30	45

Table 14-1 - FEA Load cases

14.2.2 CENTRE LINE TRANVERSE LOADS (LOAD CASE 1&4)

Figure 14-2 and Figure 14-3 display the FEA results when a load was applied at 0 degrees relative to the centre line.

- With a 250t load there is no over-stressing of the hull

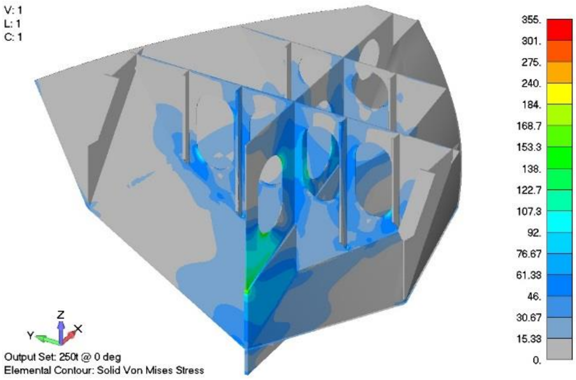


Figure 14-2 - VM stress Load Case 1

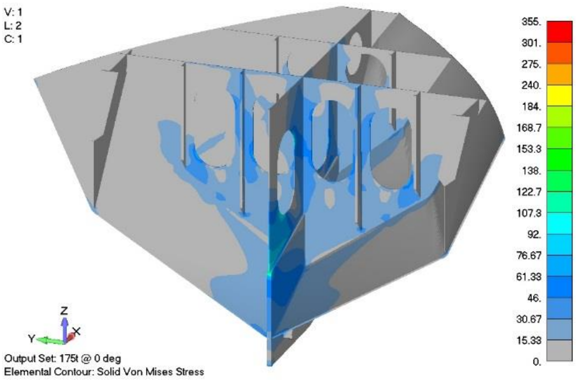


Figure 14-3 - VM stress Load Case 4

14.2.3 15 DEGREE TRANVERSE LOADS (LOAD CASE 2 & 5)

Figure 14-4 and Figure 14-5 display the FEA results when a load was applied at 15 degrees along the transverse angle from the centre line.

- With a 250t load this level of oblique loading at 15 degrees will overstress the hull, requiring reinforcement.
- With a reduced load of 175t at 15 degrees the internal stresses remain acceptable.

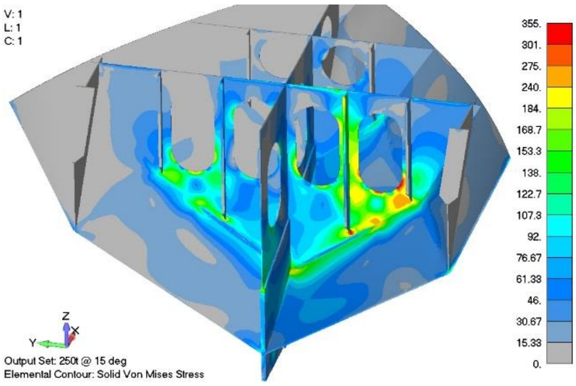


Figure 14-4 - VM stress Load Case 2

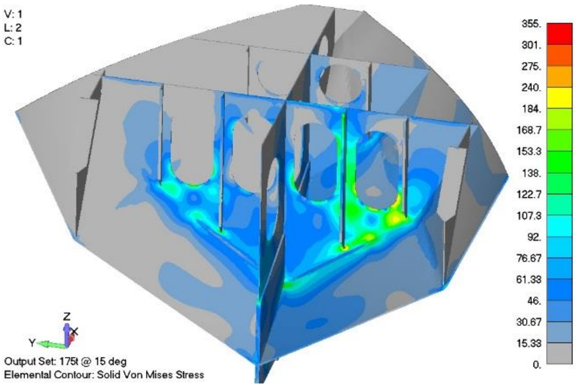


Figure 14-5 - VM stress Load Case 5

14.2.4 30 DEGREE TRANVERSE LOADS (LOAD CASE 3 & 6)

Figure 14-6 and Figure 14-7 display the FEA results when a load was applied at 30 degrees along the transverse angle from the centre line.

- With a 250t load this level of oblique loading at 30 degrees will certainly overstress the hull, requiring reinforcement.
- With a reduced load of 175t at 30 degrees the internal stresses are not acceptable.

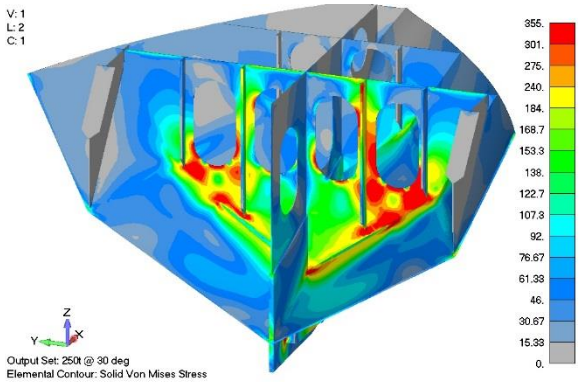


Figure 14-6 - VM stress Load Case 3

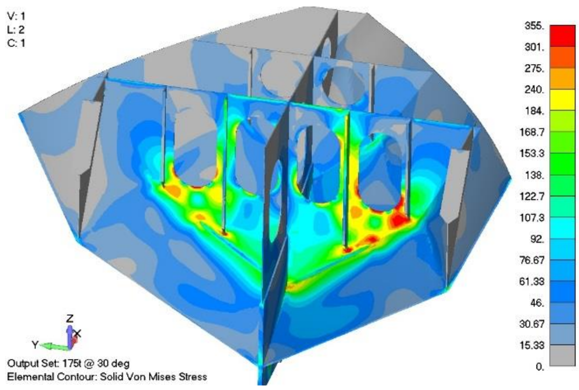


Figure 14-7 - VM stress Load Case 6

14.3 ACTUAL MOORING LOAD CASES

Further analysis was conducted to structurally assess the impact of actual mooring loads from the simulation.

Three governing cases have been initially investigated.

- Case 1 – Maximum Load Case
- Case 2 – Load Case 2 – Moderate Oblique Angle Load
- Case 3 – Load Case 88 – Large Oblique Angle Load

14.3.1 CASE 1 – MAXIMUM LOAD CASE

Figure 14-8 shows a tension angle plot for the maximum load case 1 and highlights how the maximum load of 230 Te only happen at an angle of 3 degrees.

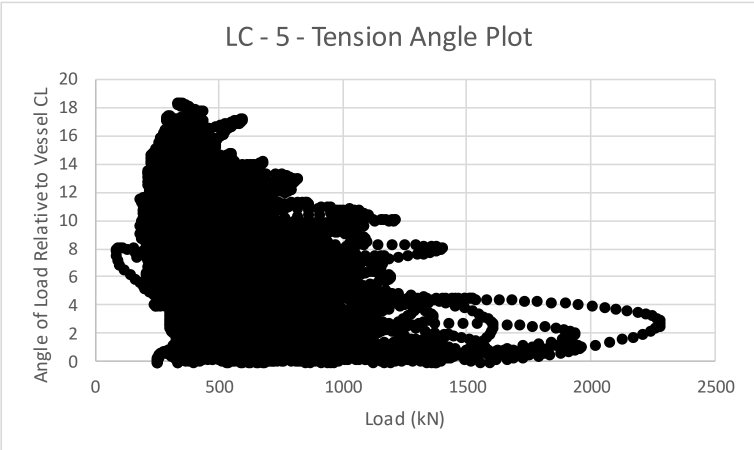


Figure 14-8 - Tension Angle Plot for maximum load case

Figure 14-9 displays the FEA results when 230 Te is applied at 3 degrees to the hull showing no overstressing of the hull.

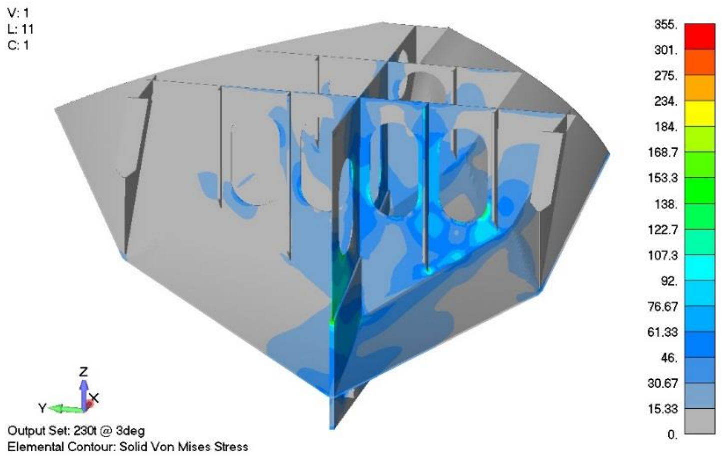


Figure 14-9 - 250 Te at 3 degrees

14.3.2 CASE 2 – LOAD CASE 2 – MODEERATE OBLIQUE LOAD CASE

Figure 14-10 shows a tension angle plot for Load Case 2 where there is a moderate to large oblique force recorded.

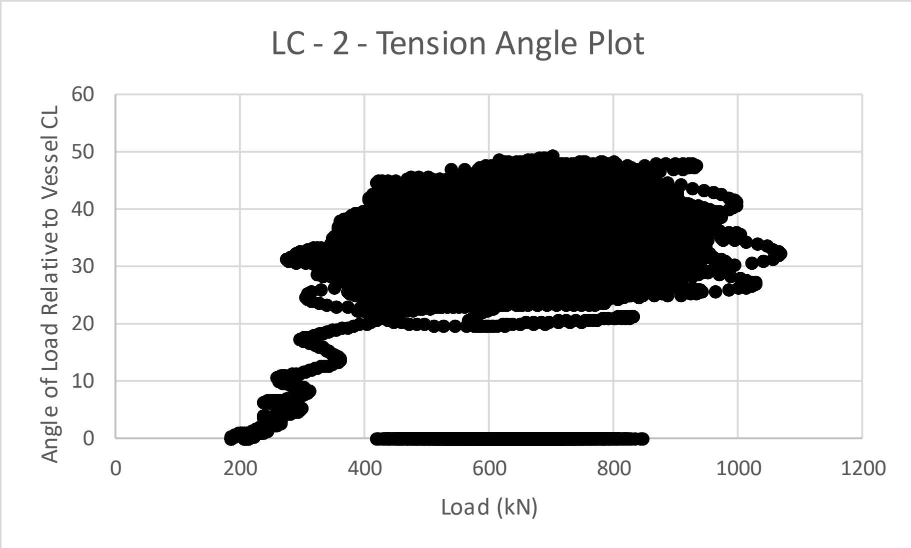


Figure 14-10 - Tension Angle Plot for Maximum when Maximum Oblique Angle was recorded

The FEA analysis ran two cases: 109te at 33 deg and 86te at 50 deg. The results of these are displayed in Figure 14-11 and Figure 14-12 respectively.

Apart from a few hot spots which, based on the overall low stress, are likely to be the result of mesh issues, these results are acceptable, subject to a more thorough fatigue assessment.

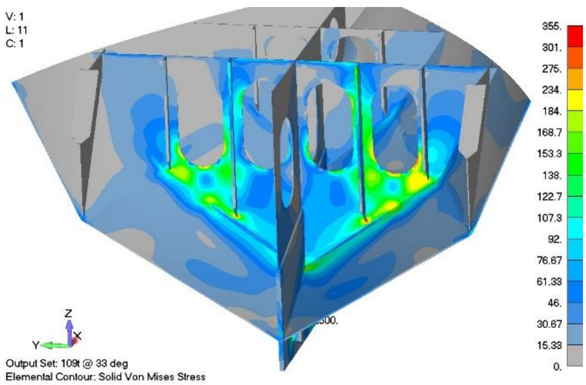


Figure 14-11 - 109Te at 33 deg

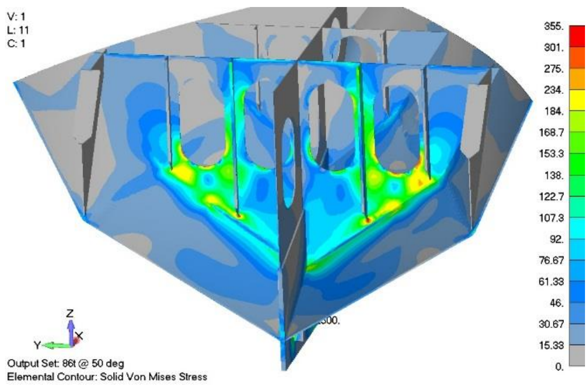


Figure 14-12 - 86 Te AT 50 deg

14.3.3 CASE 3 – LOAD CASE 88 – LARGER OBLIQUE LOAD CASE

Figure 14-10 shows a tension angle plot for Load Case 88 where there is a larger oblique force of 115t recorded.

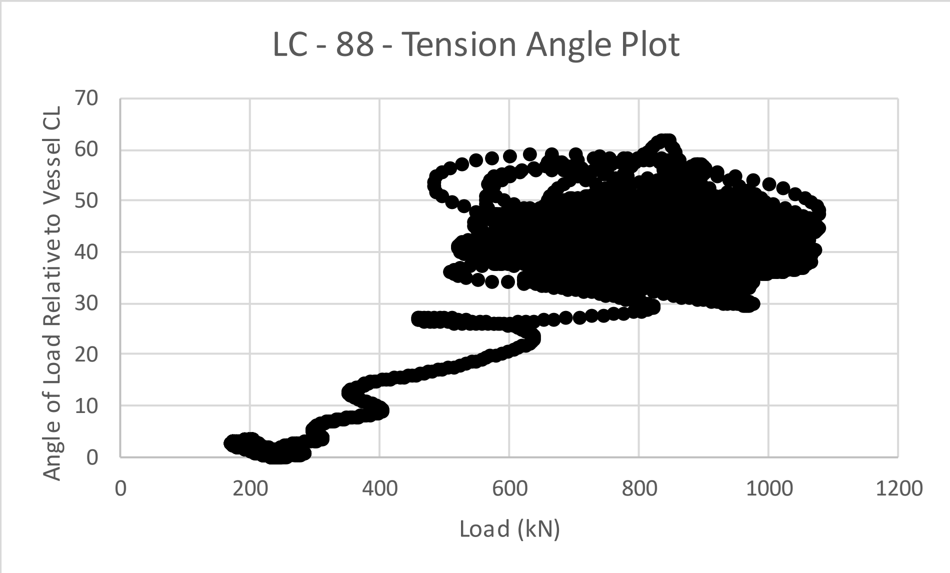


Figure 14-13 - Tension Angle Plot for Maximum when Maximum Oblique Angle was recorded

The FEA analysis for this case is presented in Figure 14-12.

There is some more significant yielding in this case which is proposed to be addressed with some minor modifications discussed in the next section.

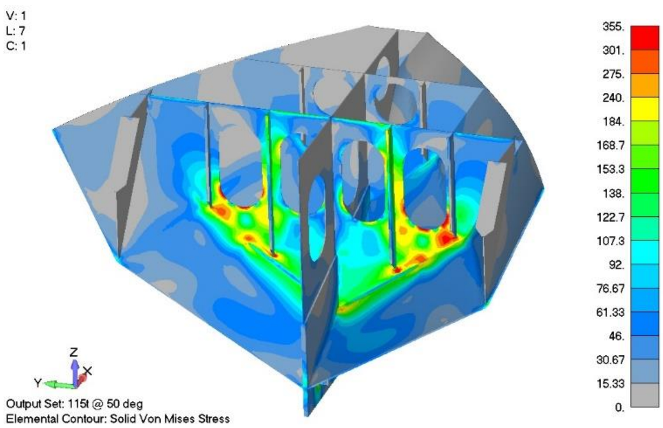


Figure 14-14 – FEA Plot with 115Te recorded at 50 deg

14.4 DISCUSSION

Case 3 representing Load Case 88 shows that some moderate over-stressing is possible.

There are three possible ways forward with regards to this over-stressing:

1. Consider a modified anchor leg attachment point to bring the load closer to the centre of the padeye. This option is discussed below and presented in Figure 14-15.
2. Allow moderate over-stressing instead of modifcations based on a rigorous inspection and monitoring regime.
    - Inspection of the hull attachment point can be achieved easily via ballasting the bow or stern of the device.
    - Inspection of Frame 25 can be achieved via access to the ballast tank
3. Consider that, even in the very worst case scenario, this area is a ballast compartment which is isolated from the rest of the vessel and will not result in sinking of capsize of the device, and furthermore it has previously been shown that it is not feasible to impact any other device or berth.
4. Consider some small steel modifications to Frame 25, for example closing man-holes or adding further stiffeners.

14.4.1 OPTION 3 MODIFICATION BEING ASSESSED

The loads within the FEA assessment are applied about 500mm from the centre of the pin as per a 250-tonne shackle. This results in a significant moment.

To achieve the potential for loads closer to the pin centre it is proposed to replace the shackle with a hull attachment appurtenance presented in Figure 14-15.

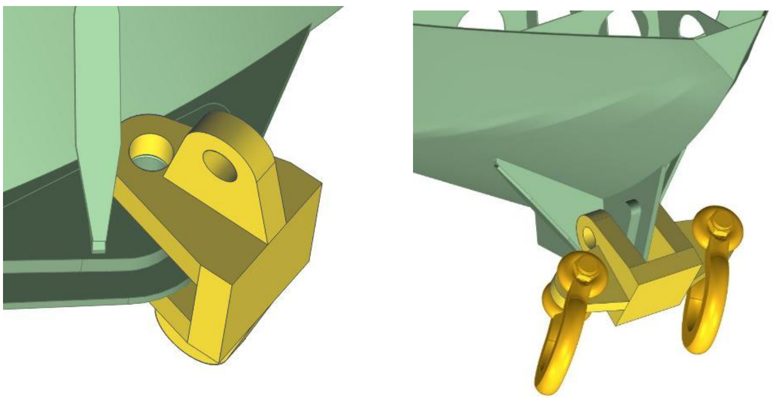


Figure 14-15 – Structural hull attachment point concept for further investigation

Further FEA tests were run to show that stresses are far more acceptable if the loads are applied directly at the pin. Figure 14-16 and Figure 14-17 show a schematic of the FEA model and two governing load cases assessed. Figure 14-18, Figure 14-19 show this.

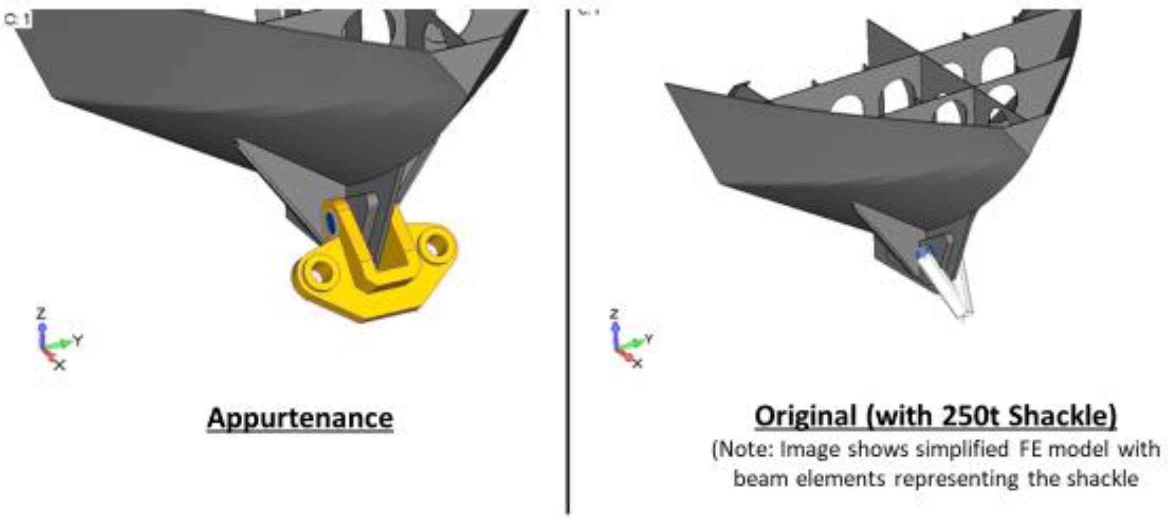


Figure 14-16 – Left – Optimised arrangement with appurtenance used to connect each mooring line, Right – Original arrangement with merely the shackle connected

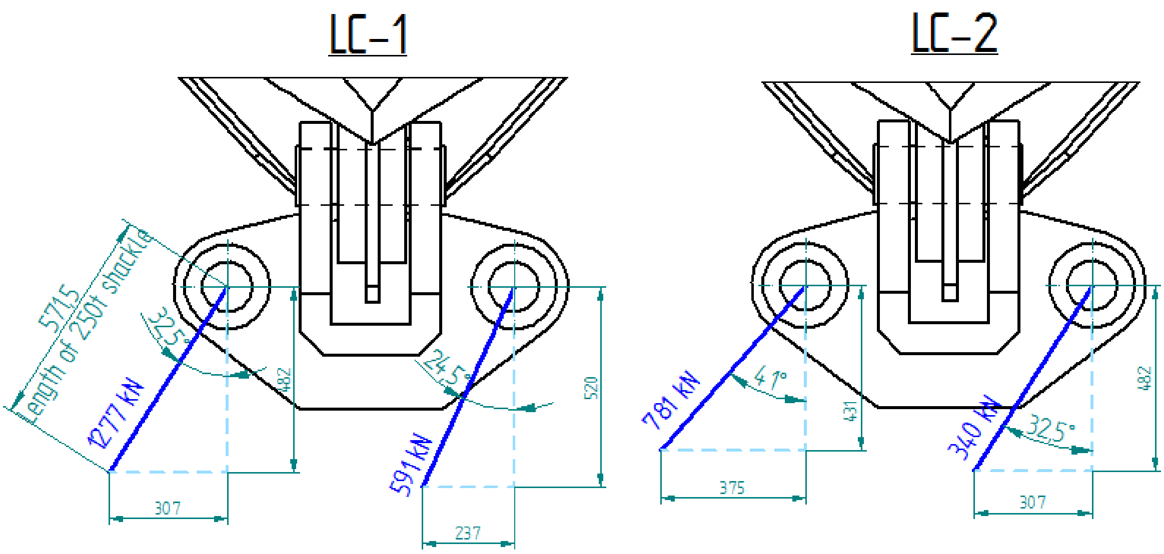


Figure 14-17 - Load case details used in FE assessment of positive effect of appertenance instead of merely a shackle

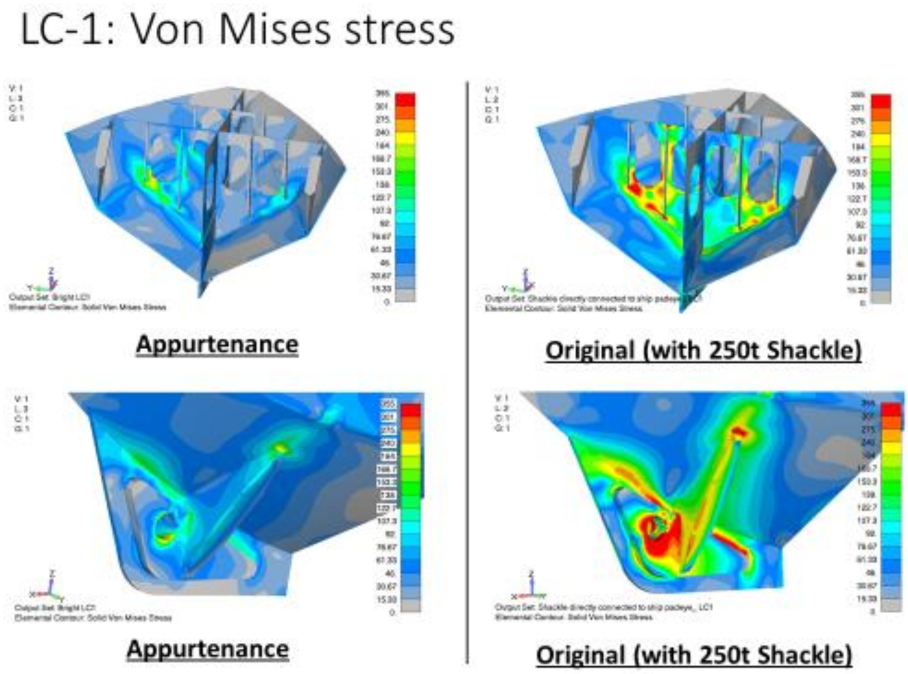


Figure 14-18 - Load Case 1 – Von Mises Stress

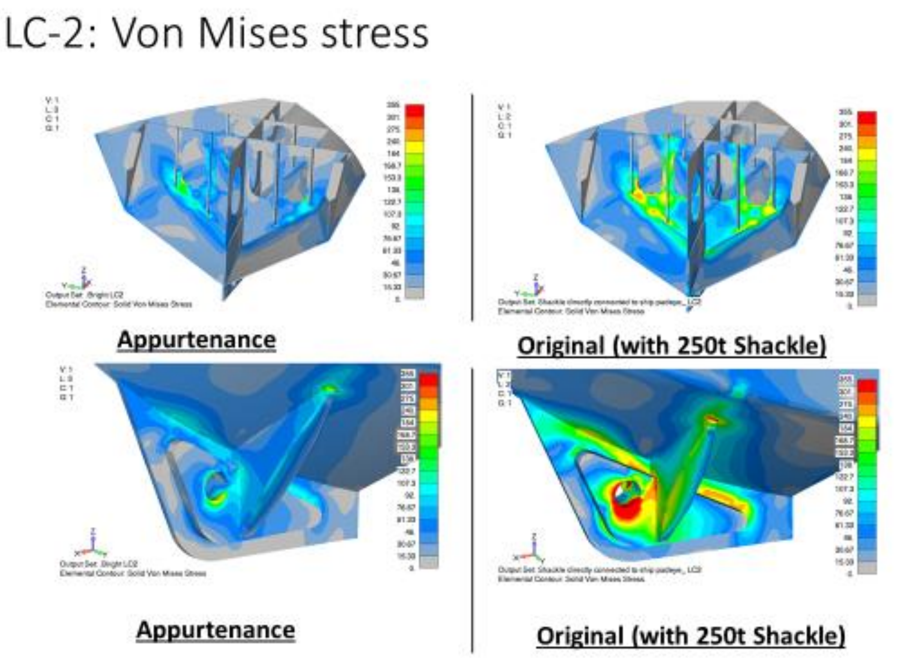


Figure 14-19 - Load Case 3 – 250t at 30 degrees

APPENDIX A - RETURN VALUES OF HS BY WAVE DIRECTION AND CURRENT SPEED

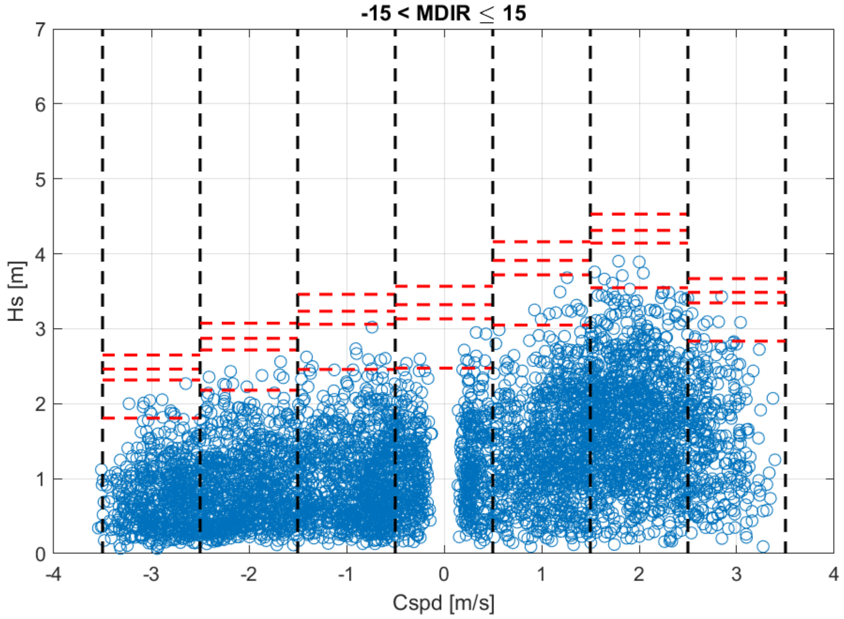


Figure A 1. Scatter plot of Hs against current speed for wave sector centred at 0°. Red lines indicate return values of Hs TO at return periods of 1, 10, 20 and 50 years.

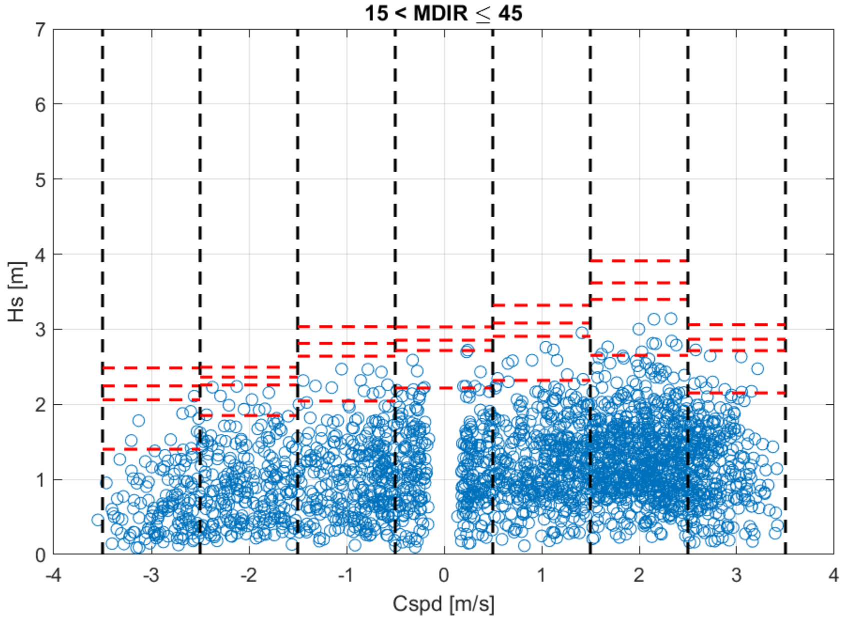


Figure A 2. Scatter plot of Hs against current speed for wave sector centred at 30°. Red lines indicate return values of Hs TO at return periods of 1, 10, 20 and 50 years.

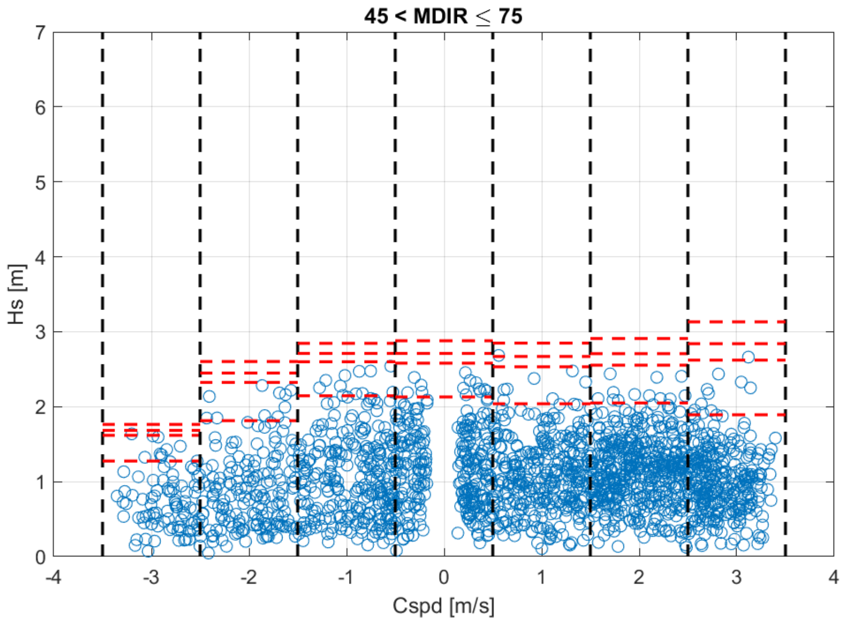


Figure A 3. Scatter plot of Hs against current speed for wave sector centred at 60°. Red lines indicate return values of Hs TO at return periods of 1, 10, 20 and 50 years.

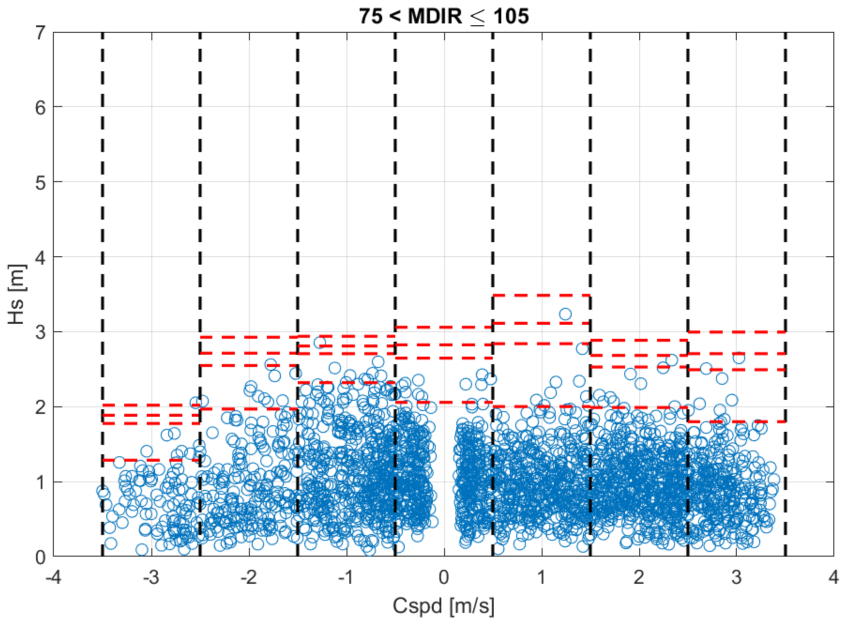


Figure A 4. Scatter plot of Hs against current speed for wave sector centred at 90°. Red lines indicate return values of Hs TO at return periods of 1, 10, 20 and 50 years.

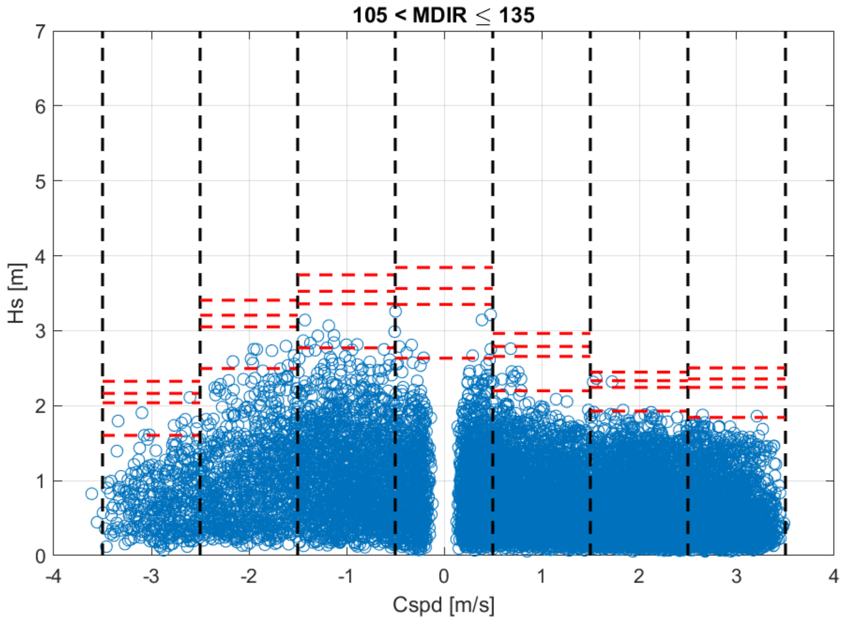


Figure A 5. Scatter plot of Hs against current speed for wave sector centred at 120°. Red lines indicate return values of Hs TO at return periods of 1, 10, 20 and 50 years.

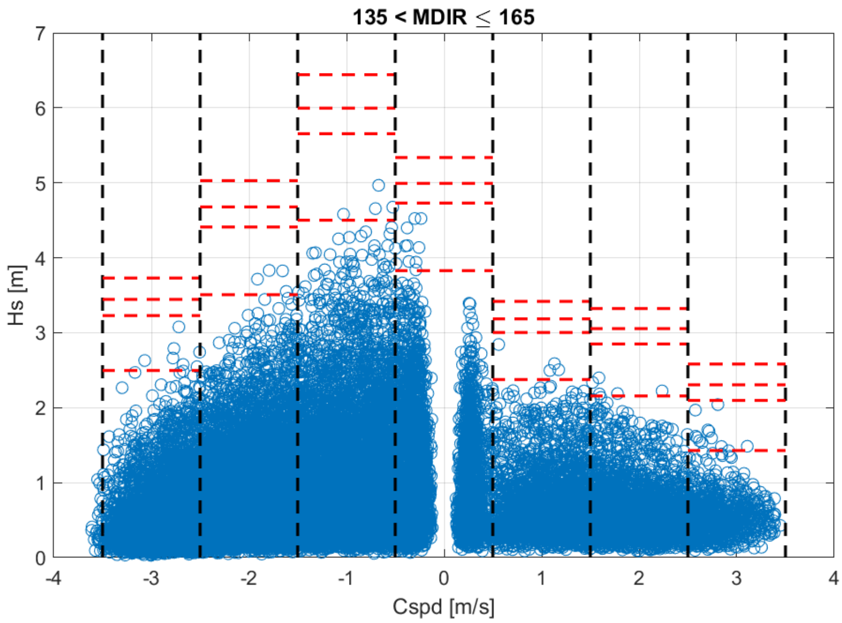


Figure A 6. Scatter plot of Hs against current speed for wave sector centred at 150°. Red lines indicate return values of Hs TO at return periods of 1, 10, 20 and 50 years.

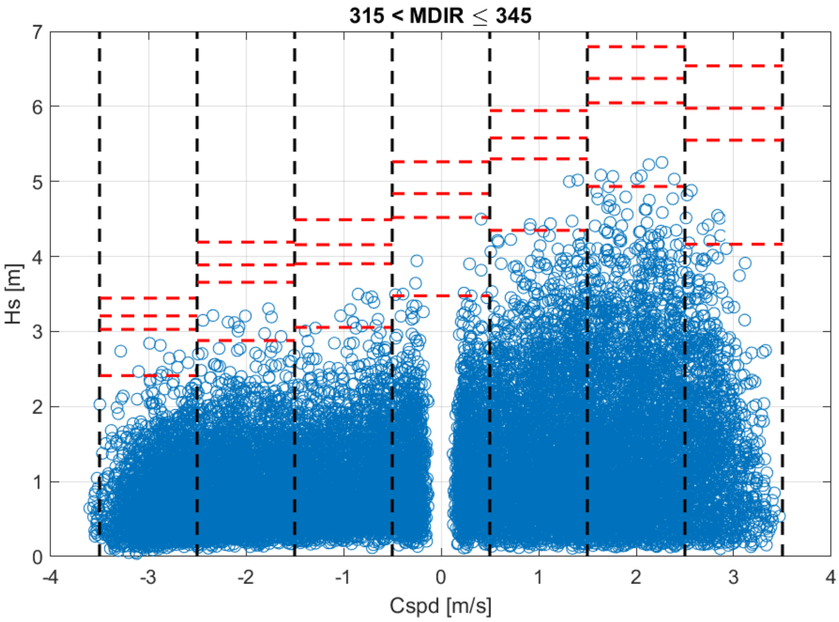


Figure A 7. Scatter plot of Hs against current speed for wave sector centred at 330°. Red lines indicate return values of Hs at return periods of 1, 10, 20 and 50 years.

APPENDIX B - FITTED WEIBULL DISTRIBUTIONS FOR COMBINED WAVE AND CURRENT

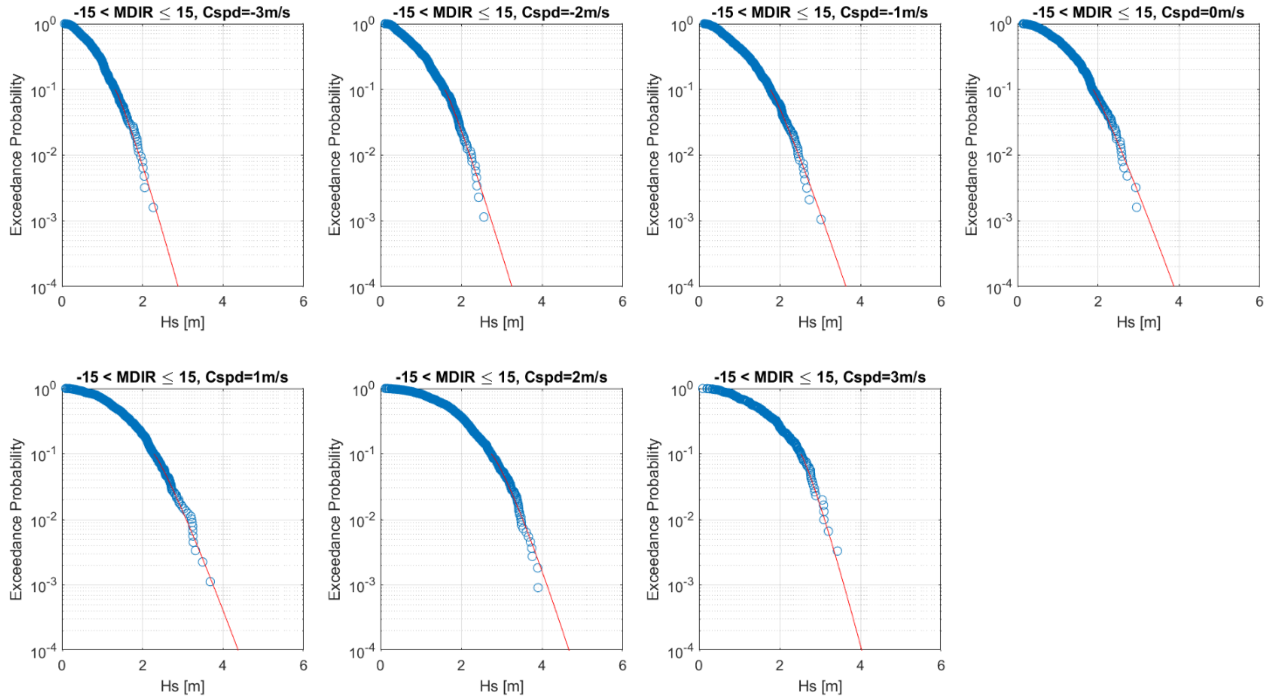


Figure A 8. Exceedance probability of Hs, binned by wave direction and current speed for observations (blue circles) and fitted Weibull distributions (red lines).

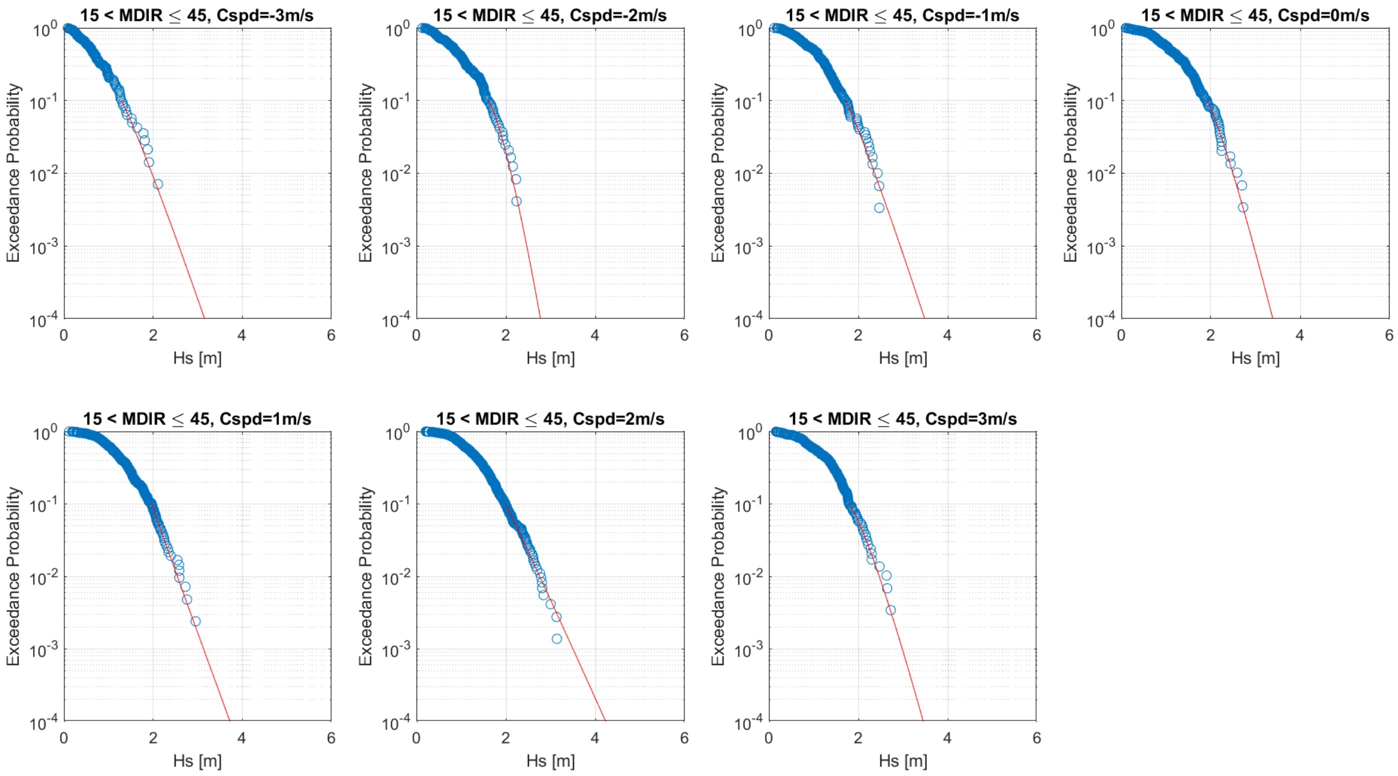


Figure A 9. Exceedance probability of Hs, binned by wave direction and current speed for observations (blue circles) and fitted Weibull distributions (red lines).

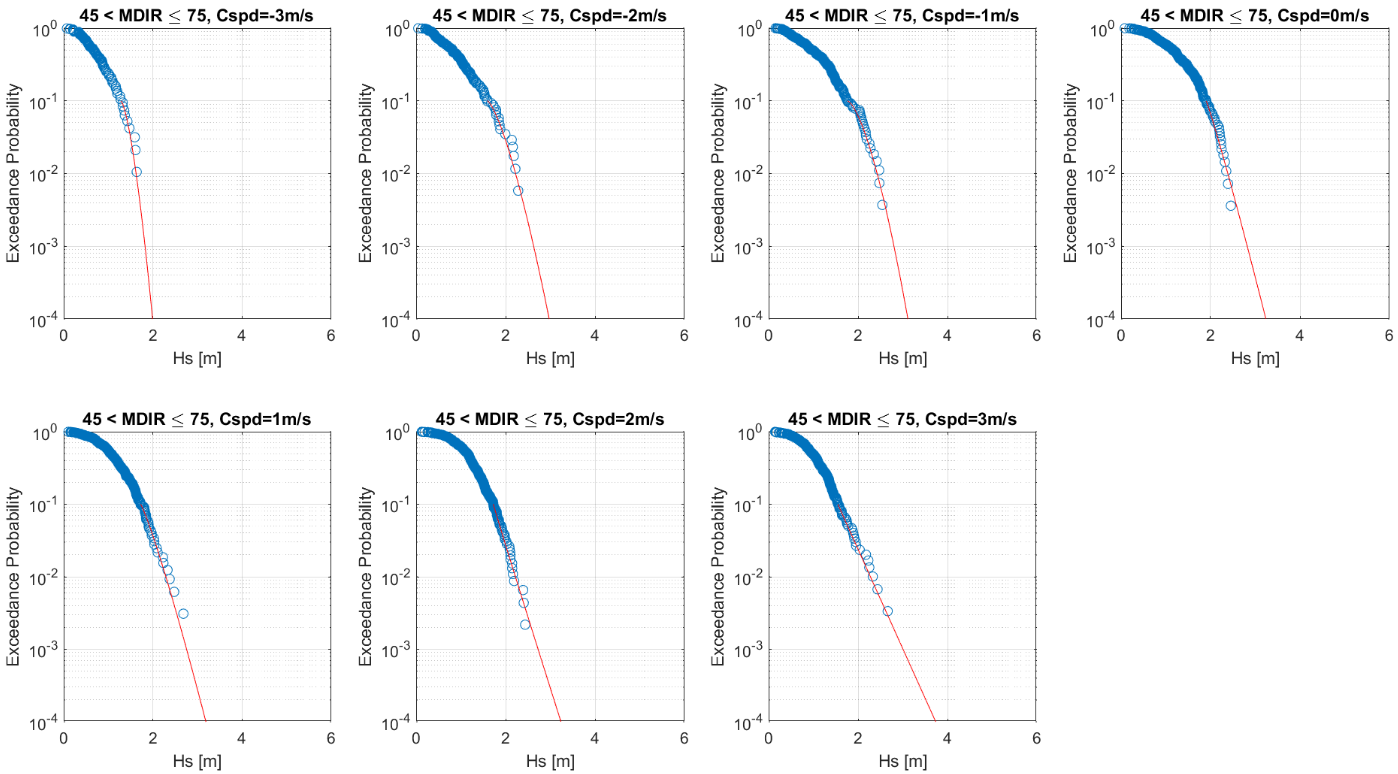


Figure A 10. Exceedance probability of Hs, binned by wave direction and current speed for observations (blue circles) and fitted Weibull distributions (red lines).

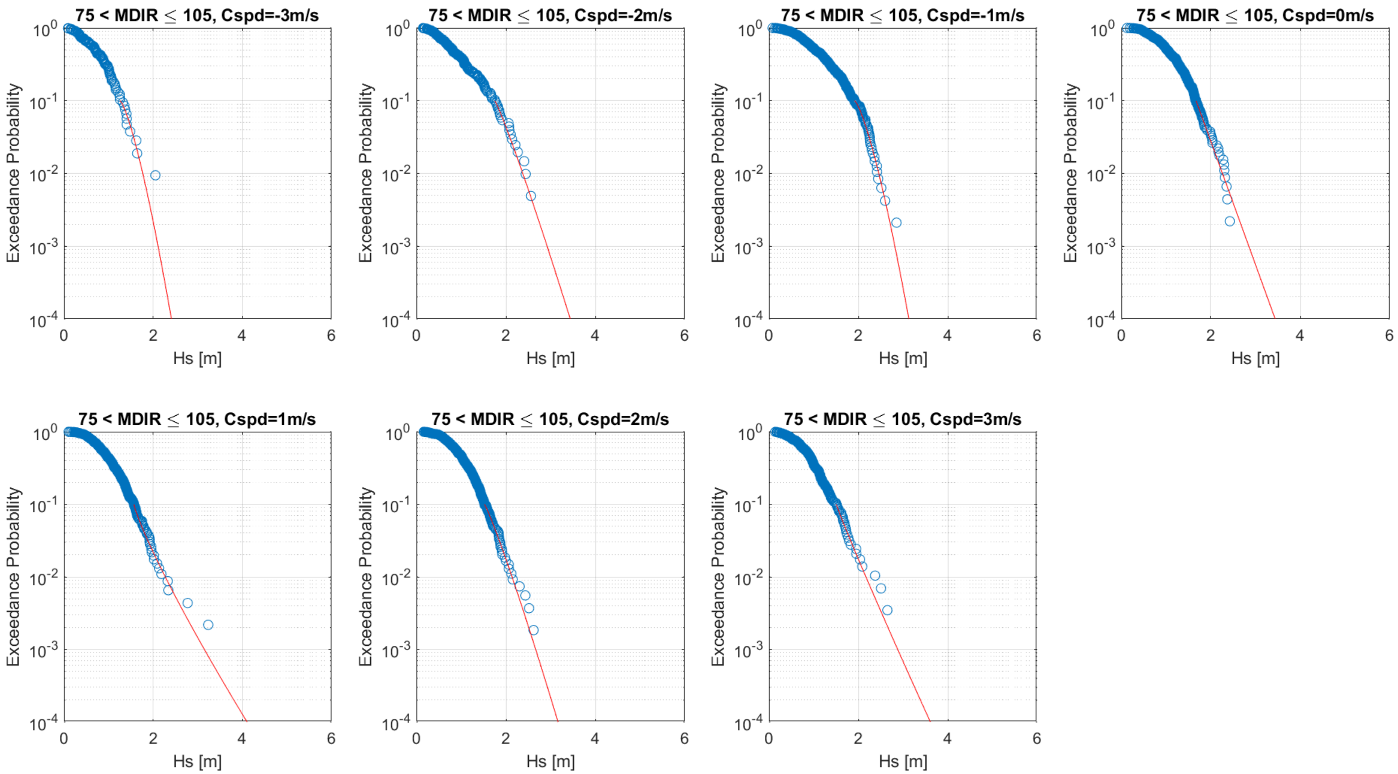


Figure A 11. Exceedance probability of Hs, binned by wave direction and current speed for observations (blue circles) and fitted Weibull distributions (red lines).

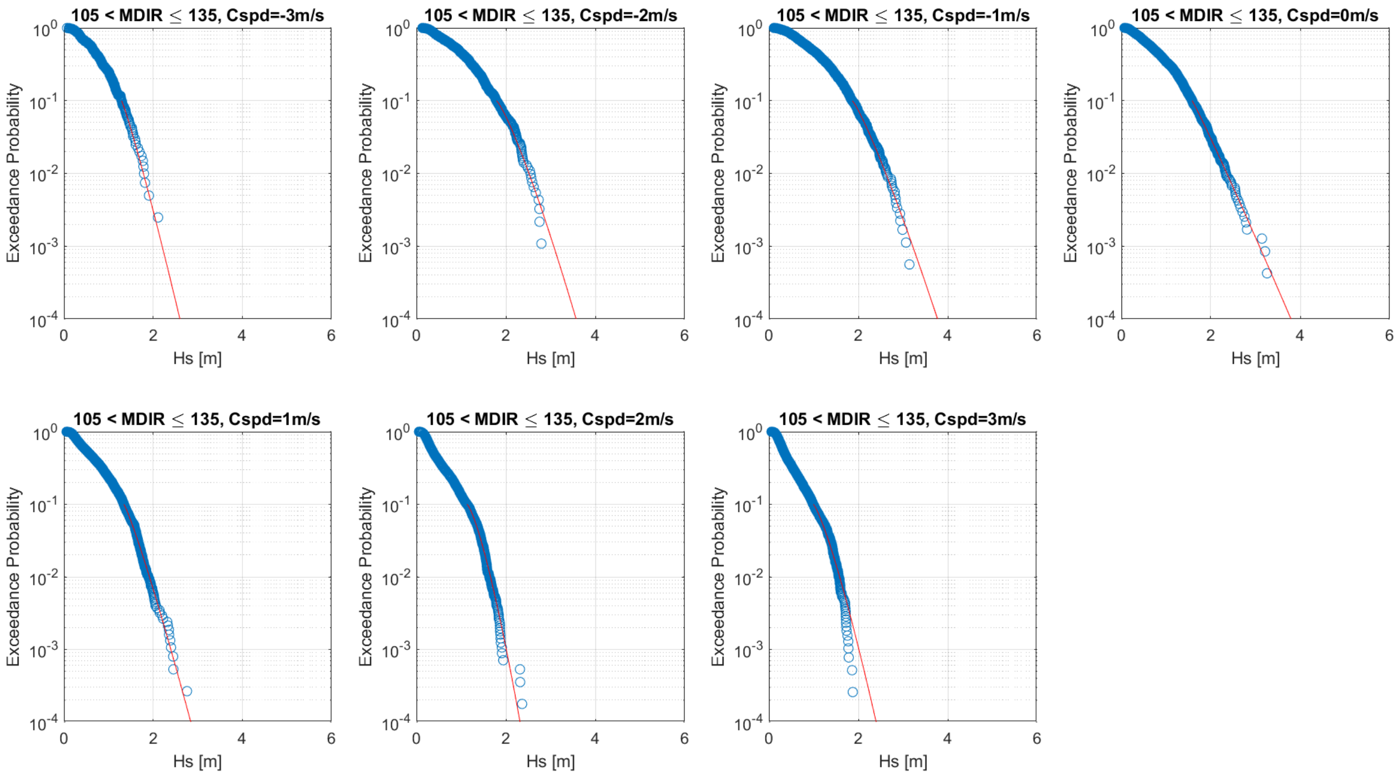


Figure A 12. Exceedance probability of Hs, binned by wave direction and current speed for observations (blue circles) and fitted Weibull distributions (red lines).

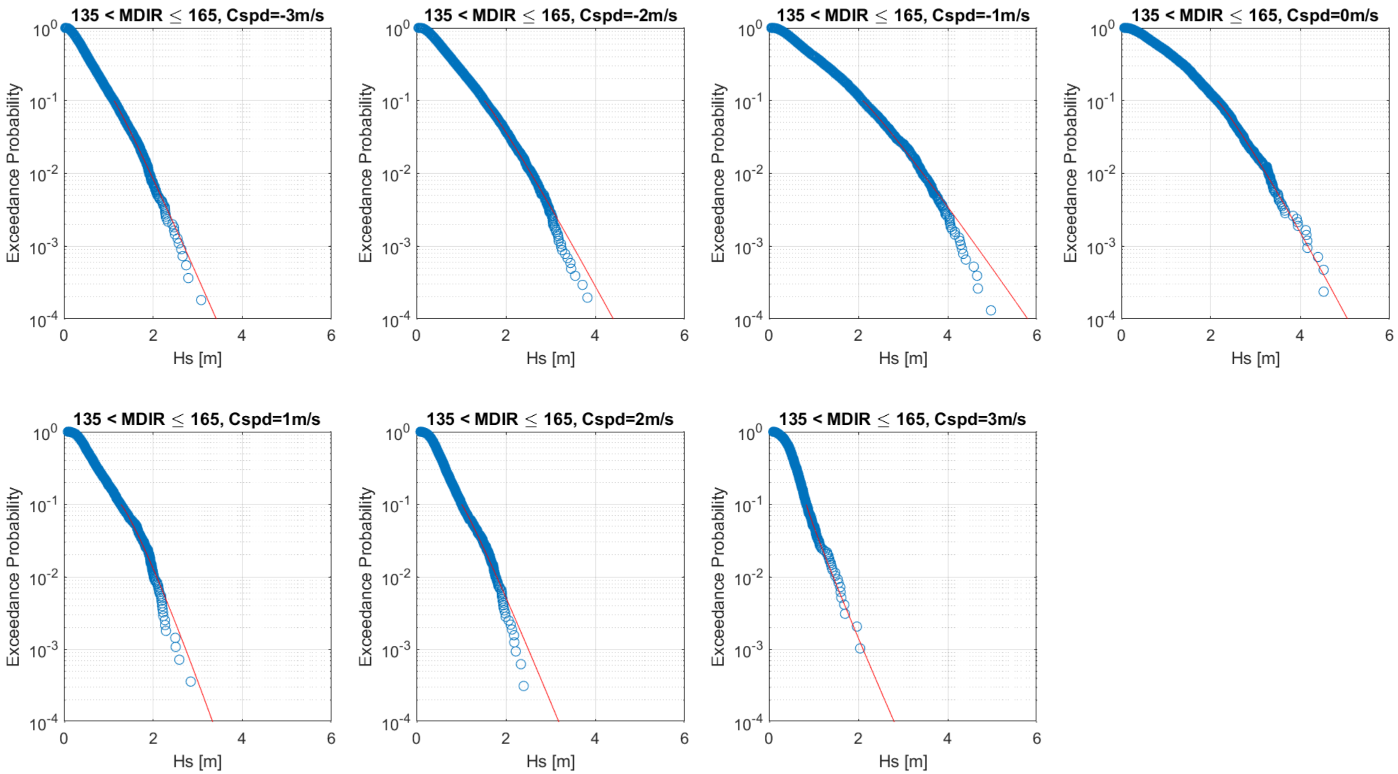


Figure A 13. Exceedance probability of Hs, binned by wave direction and current speed for observations (blue circles) and fitted Weibull distributions (red lines).

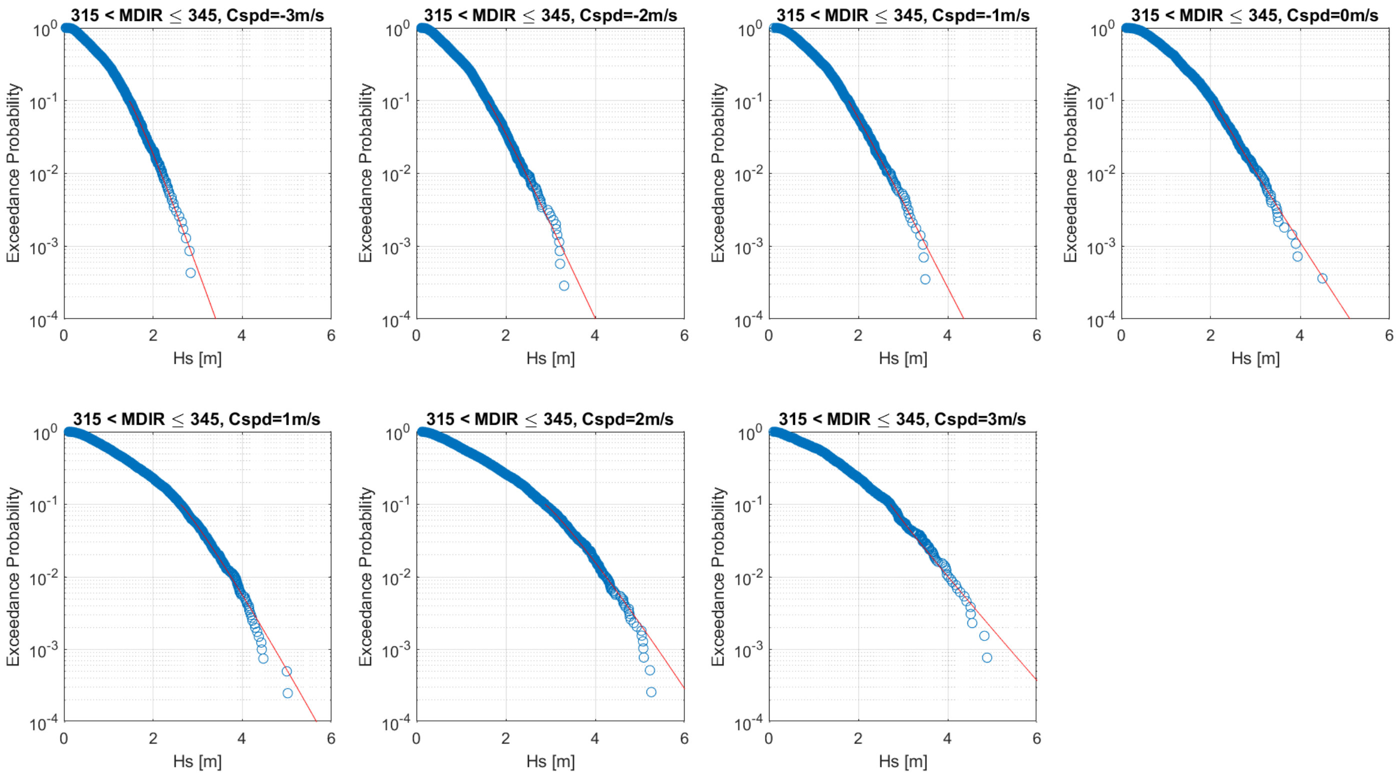


Figure A 14. Exceedance probability of Hs, binned by wave direction and current speed for observations (blue circles) and fitted Weibull distributions (red lines).

APPENDIX C - RELATION BETWEEN WINDSPEED AND HS

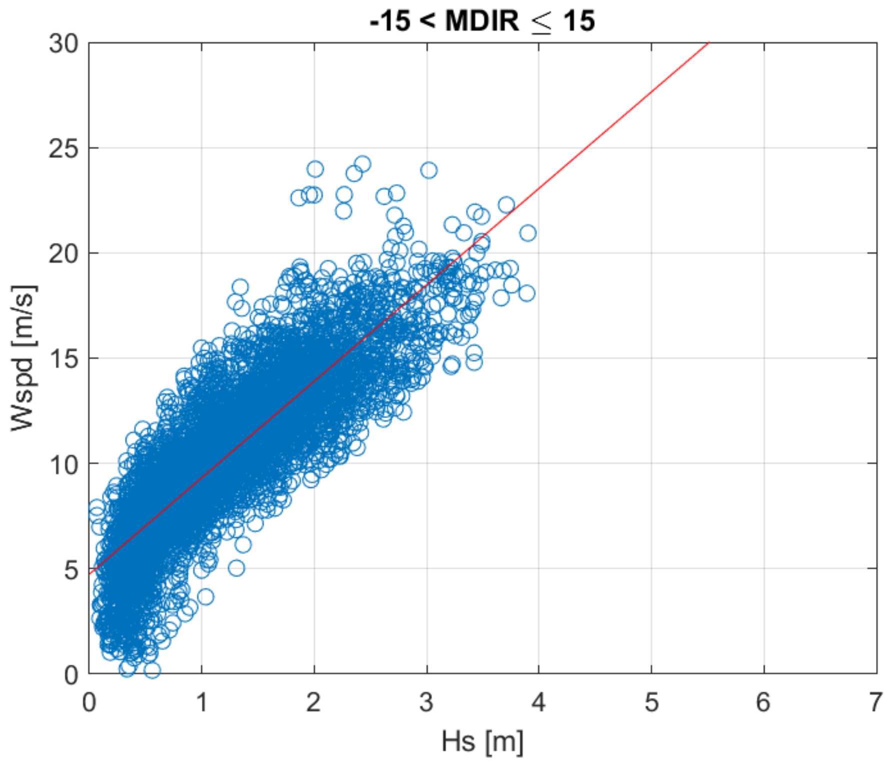


Figure A 15. Linear regression of windspeed on Hs for wave direction sector centred at 0°.

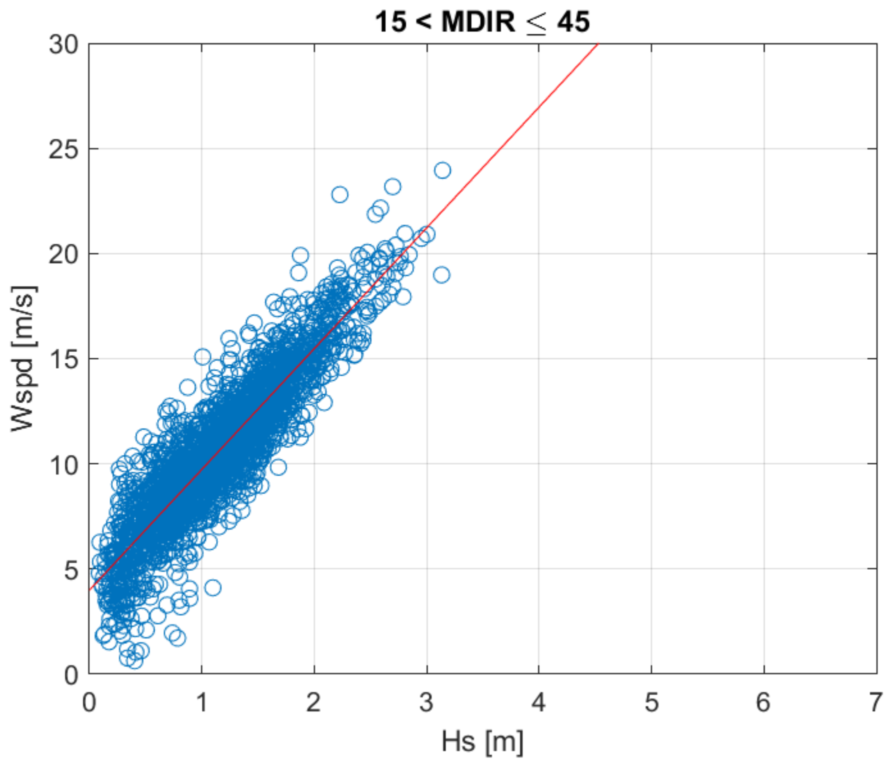


Figure A 16. Linear regression of windspeed on Hs for wave direction sector centred at 30°.

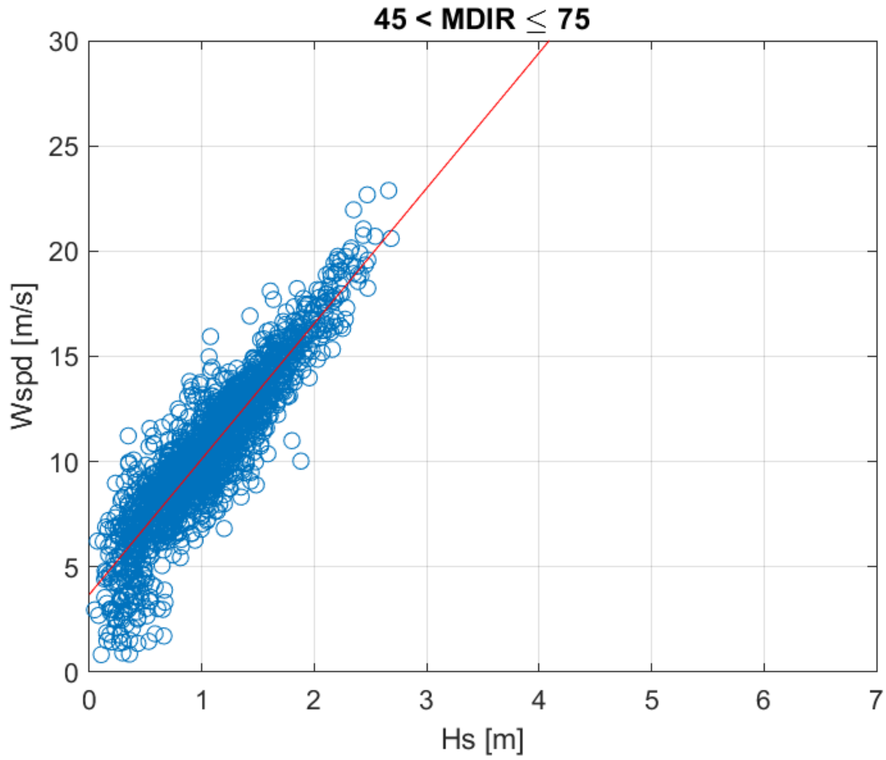


Figure A 17. Linear regression of windspeed on Hs for wave direction sector centred at 60°.

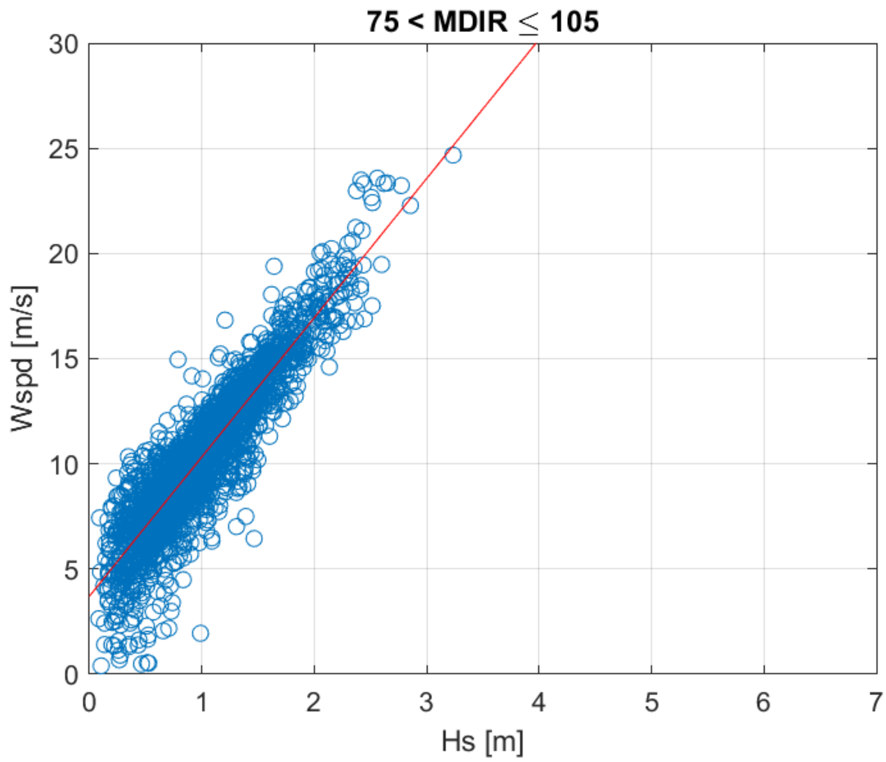


Figure A 18. Linear regression of windspeed on Hs for wave direction sector centred at 90°.

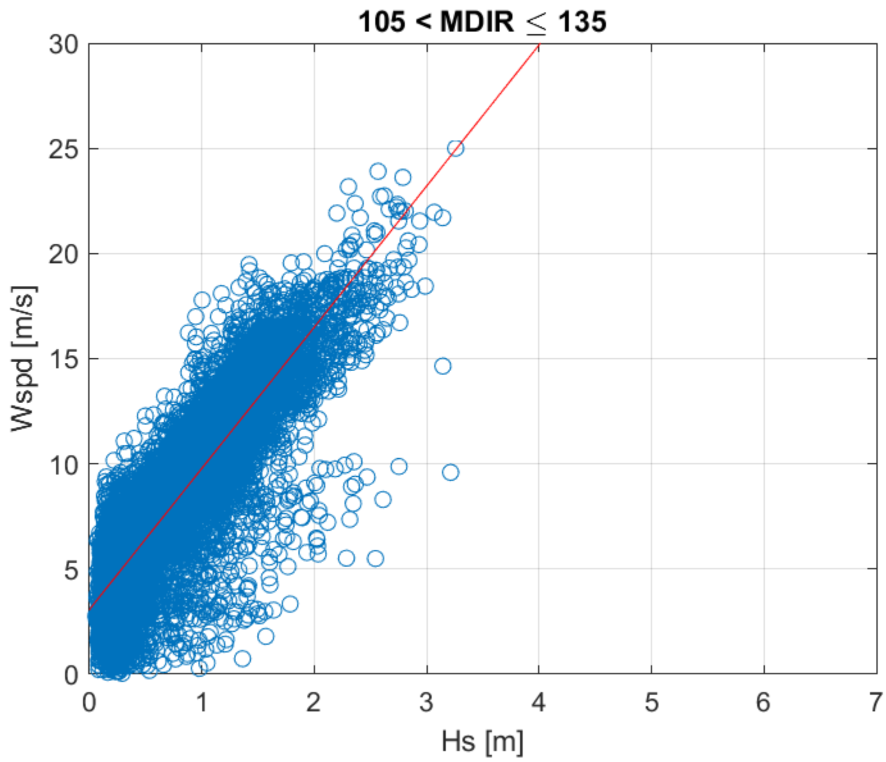


Figure A 19. Linear regression of windspeed on Hs for wave direction sector centred at 120°.

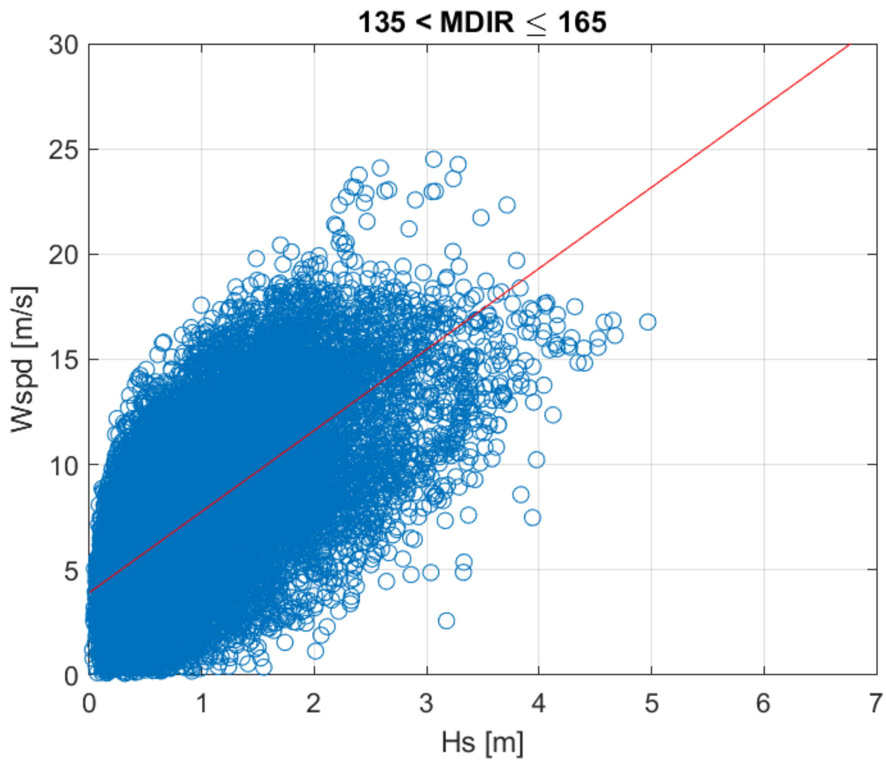


Figure A 20. Linear regression of windspeed on Hs for wave direction sector centred at 150°.

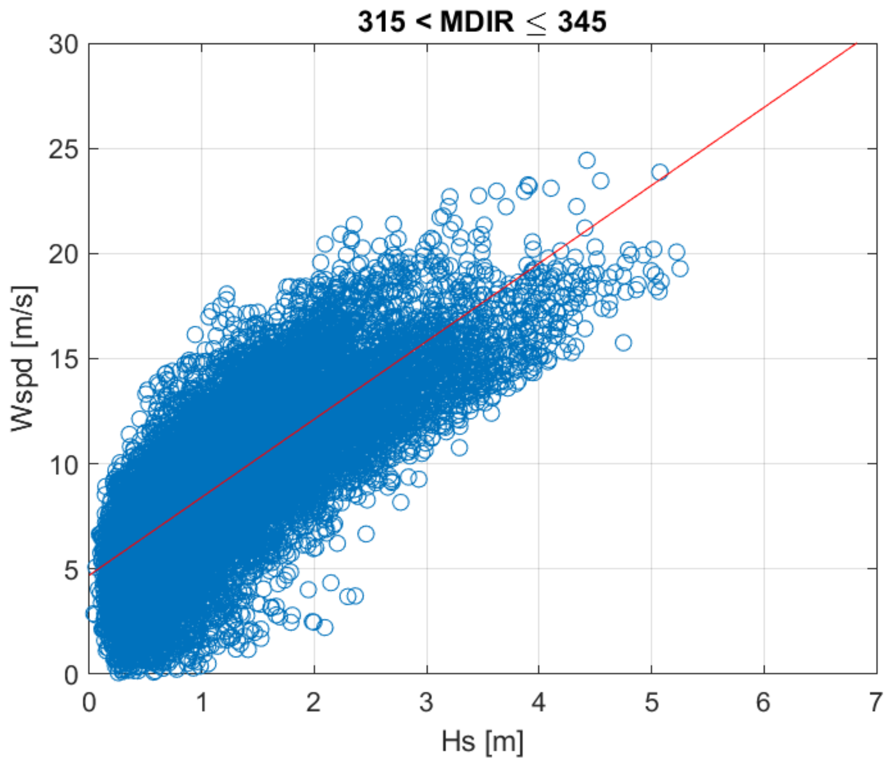


Figure A 21. Linear regression of windspeed on Hs for wave direction sector centred at 330°.

APPENDIX D - SCATTER PLOTS BINNED BY WAVE DIRECTION AND CURRENT SPEED

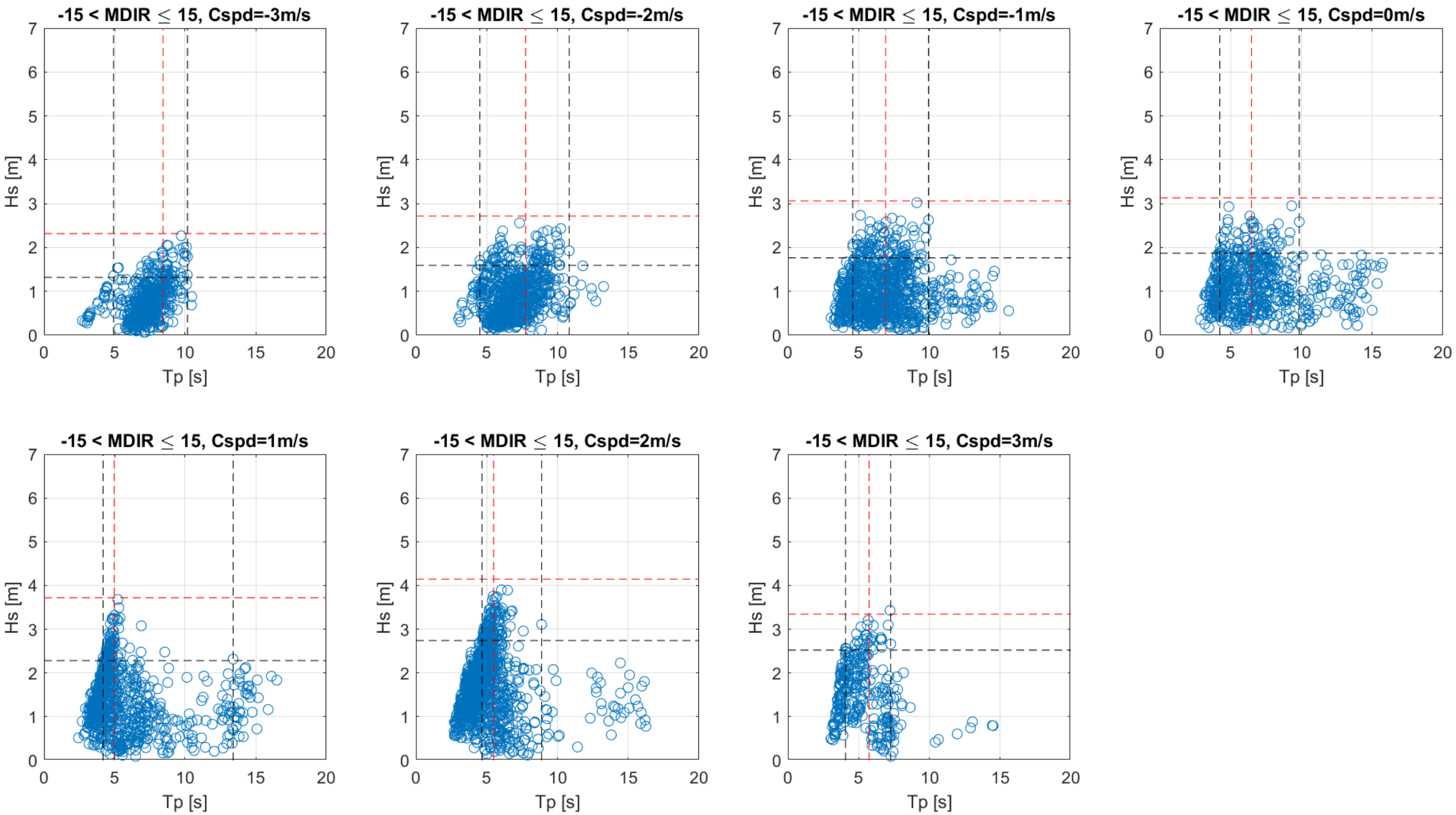


Figure A 22. Scatter plots of Hs against Tp binned by wave direction and current speed. Horizontal lines indicate 90% quantile and 10-year return value of Hs for the bin. Vertical lines indicate min, mean and max Tp for Hs above the 90% quantile.

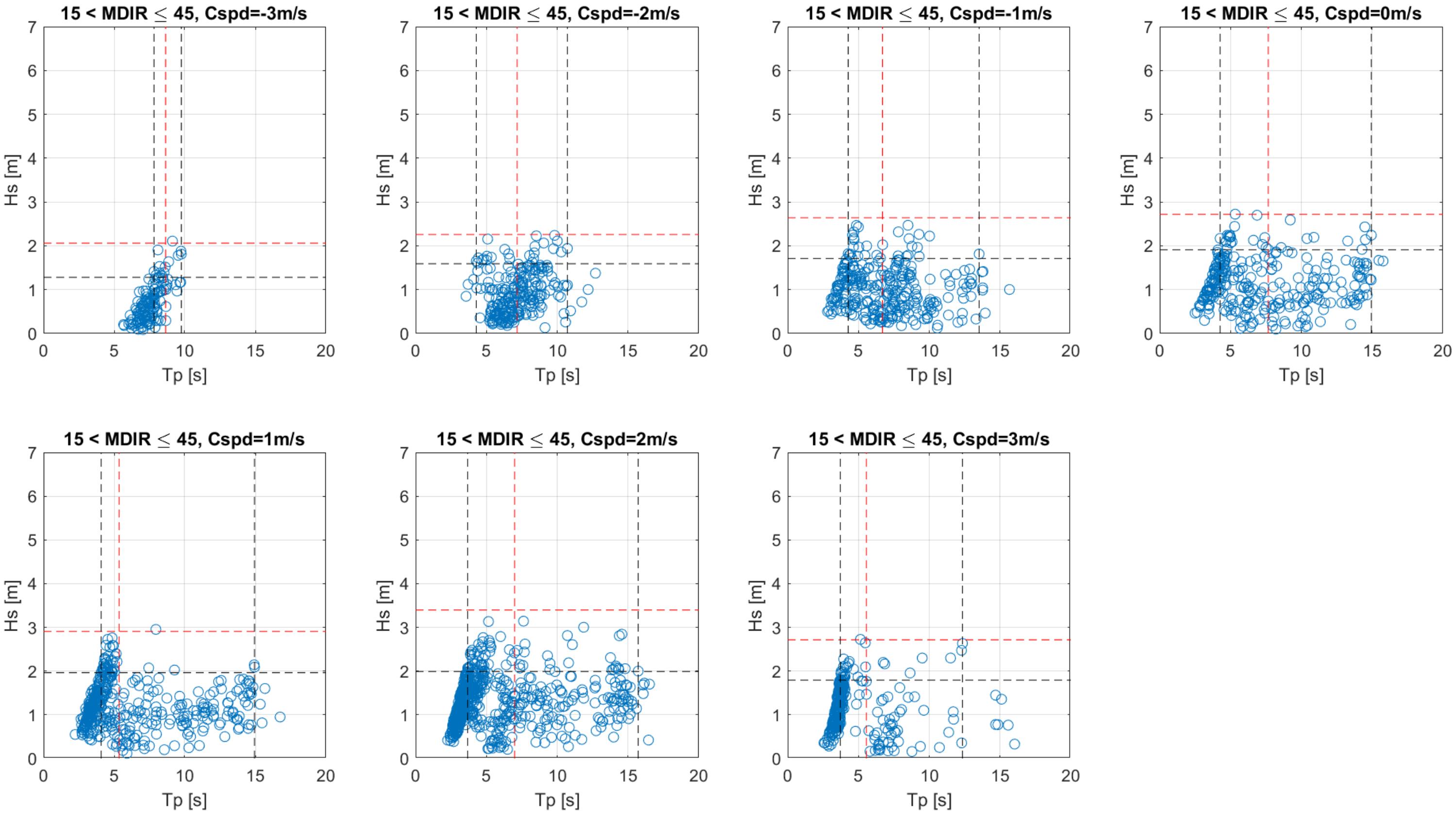


Figure A 23. Scatter plots of Hs against Tp binned by wave direction and current speed. Horizontal lines indicate 90% quantile and 10-year return value of Hs for the bin. Vertical lines indicate min, mean and max Tp for Hs above the 90% quantile.

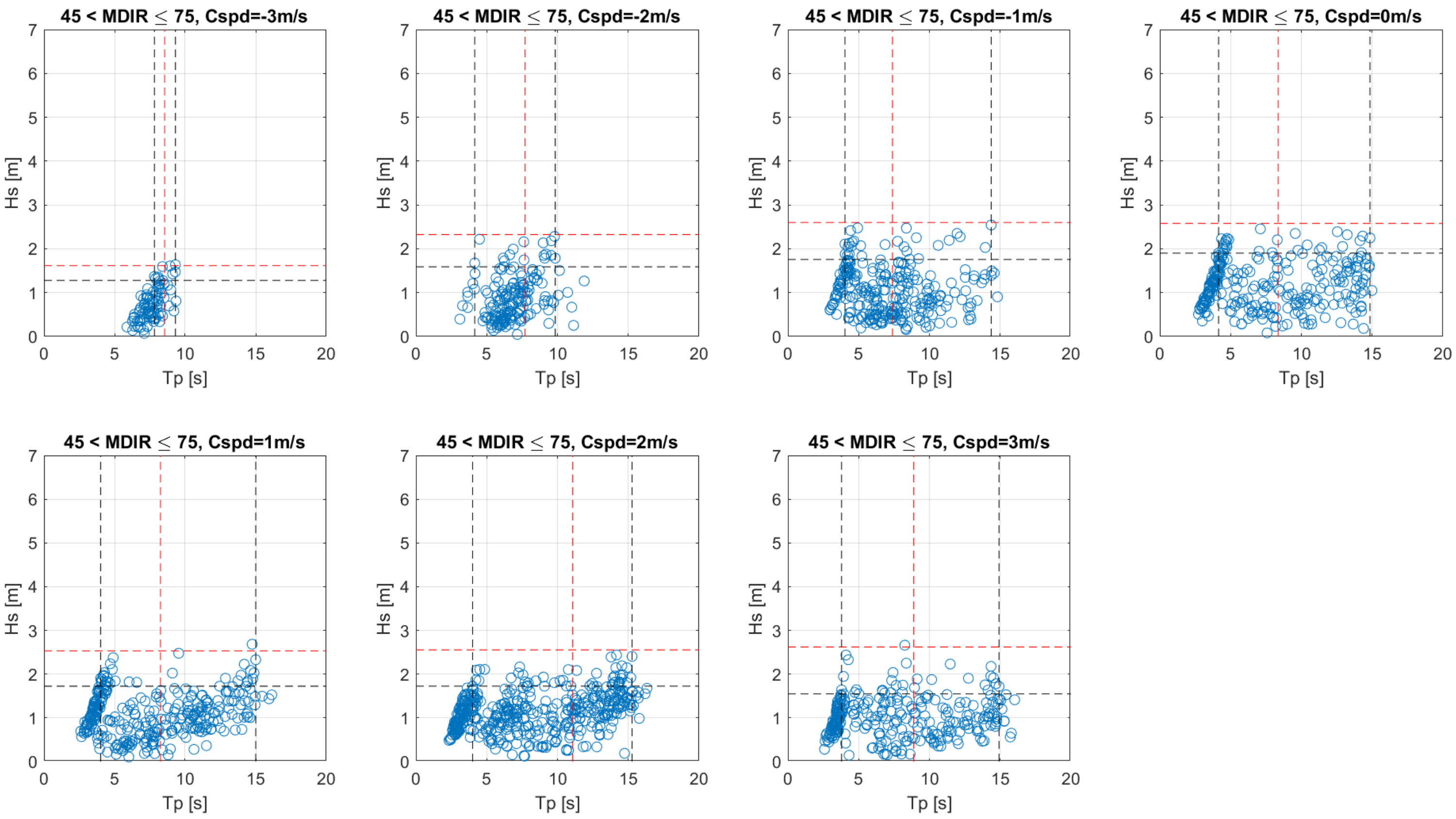


Figure A 24. Scatter plots of Hs against Tp binned by wave direction and current speed. Horizontal lines indicate 90% quantile and 10-year return value of Hs for the bin. Vertical lines indicate min, mean and max Tp for Hs above the 90% quantile.

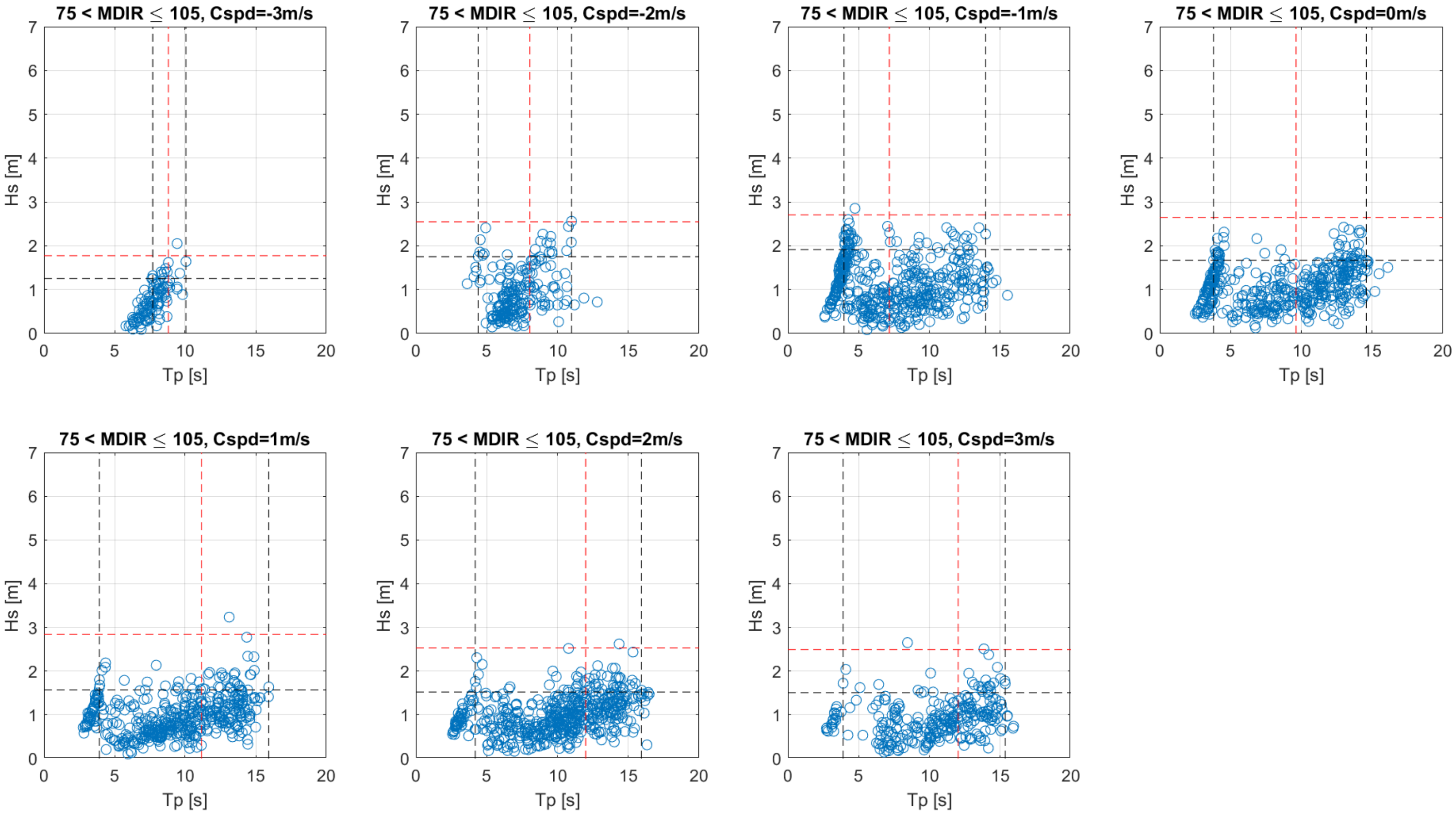


Figure A 25. Scatter plots of Hs against Tp binned by wave direction and current speed. Horizontal lines indicate 90% quantile and 10-year return value of Hs for the bin. Vertical lines indicate min, mean and max Tp for Hs above the 90% quantile.

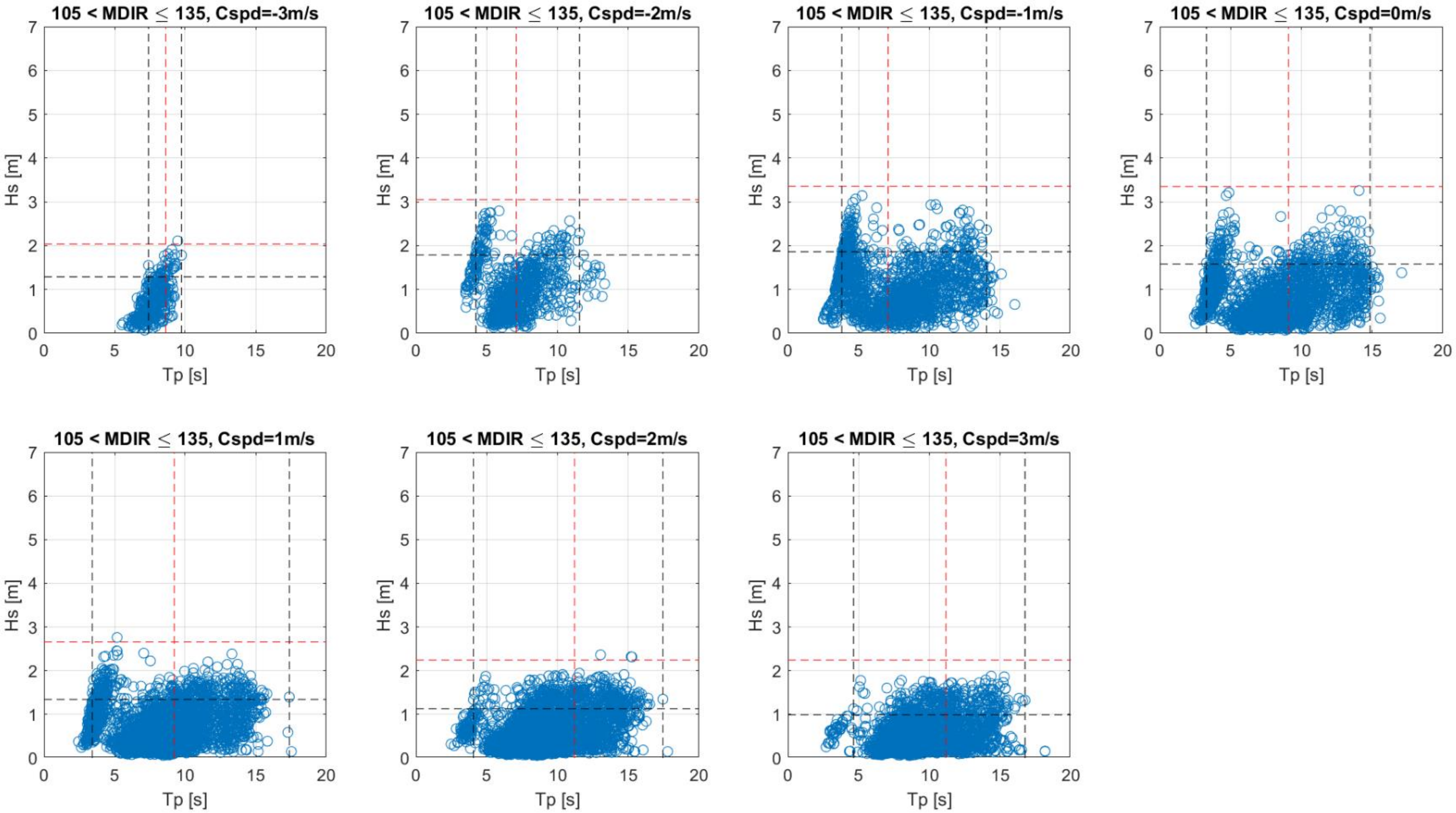


Figure A 26. Scatter plots of Hs against Tp binned by wave direction and current speed. Horizontal lines indicate 90% quantile and 10-year return value of Hs for the bin. Vertical lines indicate min, mean and max Tp for Hs above the 90% quantile.

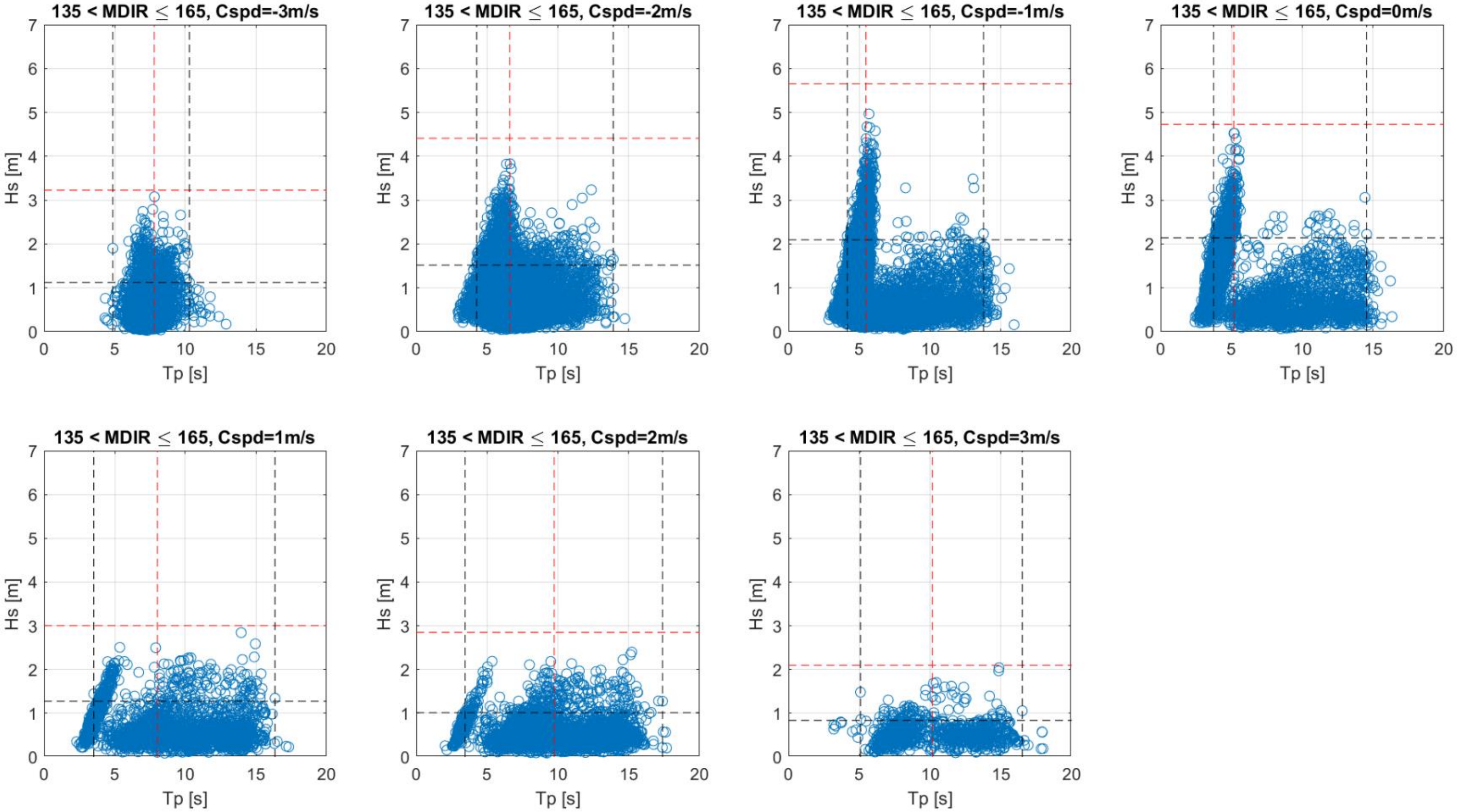


Figure A 27. Scatter plots of Hs against Tp binned by wave direction and current speed. Horizontal lines indicate 90% quantile and 10-year return value of Hs for the bin. Vertical lines indicate min, mean and max Tp for Hs above the 90% quantile.

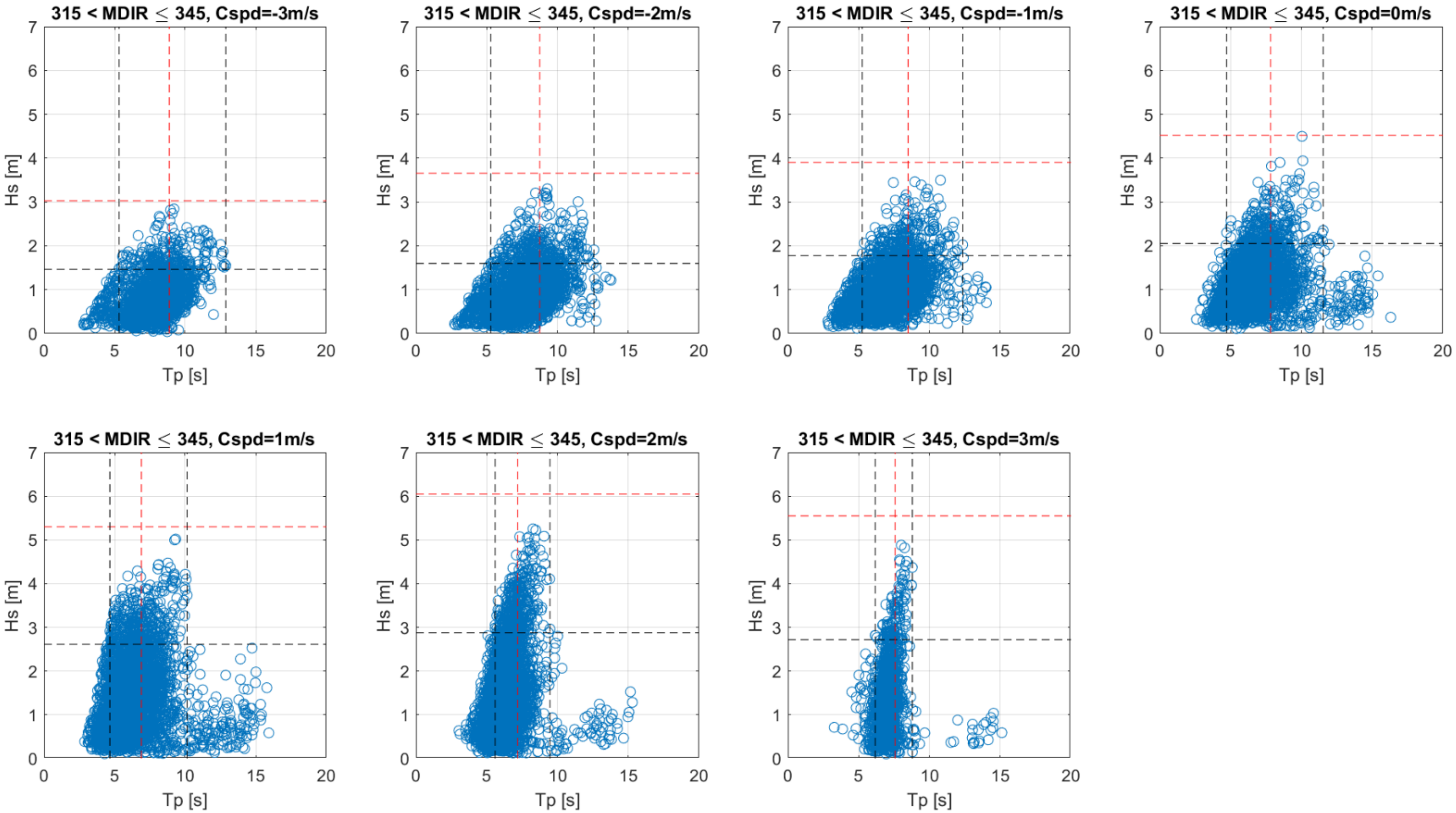


Figure A 28. Scatter plots of Hs against Tp binned by wave direction and current speed. Horizontal lines indicate 90% quantile and 10-year return value of Hs for the bin. Vertical lines indicate min, mean and max Tp for Hs above the 90% quantile.

APPENDIF E - DRAG COEFFICIENT ESTIMATE FOR TURBINE BLADES

It is noted that under normal operating conditions, as the current speed increases, the blades pitch to give the optimum energy to the generator – this gives a varying drag and load profile.

A conservative approach using the maximum thrust and maximum blade pitch on both turbines, which occurs at 2.5m/s. Above this current speed the blades feather and load shed reducing the axial thrust.

Two methods of calculating the thrust (or thrust coefficient) are proposed below

Method 1

At this current speed the Rotor Power is maximum (1MW) – The actual available power through the blades is 1.35 MW.

The total power through the turbine is given by

$$P = \frac{16}{27} 0.5 S \rho v^3$$

Where 16/27 is Betz efficiency
S is the Swept Area

The thrust force T on the rotor is given by

$$T = P/v$$

$$T = \frac{1350000}{2.5} = 540kN$$

The Drag or Thrust (for a turbine) in this case is given by

$$C_T = \frac{T}{{}^{1}\!/_{2}\, \rho S v^2}$$

Rearranging the equations above

$$C_T = \frac{P}{{}^{1}\!/_{2}\, \rho S v^3} = 0.59$$

Method 2

From turbine momentum theory, ref [17]

$$T = 0.5 \rho S v^2 [4a(1-a)]$$

Where a is the axial induction factor (ratio of change of velocity in front of the turbine to the free stream velocity)

T is a maximum when a =0.5, but this is an unrealistic value as this means the velocity in front of the turbine = 0 i.e. it acts like a solid. The Power Coefficient is given by ref [17]

$$C_P = 4a(1-a)^2$$

$$C_P = \frac{Rotor\ Power}{Power\ in\ Current}$$

$$C_P = \frac{1MW}{2.27\ MW} = 0.44$$

Rearranging the Power Coefficient to find a

$$a = 0.154$$

Then

$$T = 0.5\rho S v^2[4a(1-a)] = 464kN$$

So

$$C_T = \frac{T}{{}^1\!/_2\, \rho S v^2}$$

$$C_T = 0.51$$

This is the coefficient of thrust at 2.5m/s

The Coefficient of Thrust is also required at 3.5 and 3.6 m/s. The power available at these velocities is 6.236 MW and 6.785 MW respectively Cp = 0.160 and 0.1474.

The corresponding Thrust T = 297 and 289 kN, this gives

$$C_T = 0.167 \; and \; 0.162$$

APPENDIX F – RISK ASSESSMENT

Risk Id.	Risk Description	Cause of Risk	Consequence of Risk	Prob (1-4)	Impact (1-4)	Risk Score	Risk Response Type	Risk Prevention Measure Description	Risk Trigger	Prob (1-4)	Impact (1-4)	Risk Score	Response if risk becomes an issue	Risk Owner
1	Blade failure / break off - causing subsequent damage to device	1. An object collides with the blade. 2. Blade in contact with seabed.	Damage to assets - particularly Power train, (bearings, gearbox) + structural	2	3	6	Mitigate Transfer	1. Measure the draft before mooring the platform with the blades assembled on it. 2. Install a sounding line for measuring the draft below the platform. 3. When possible, moor where sea depth is 110% of platform draft (including blades). 4. Insurance for Property Damage and Third Party Liability in place.	4. Vibration 1. Draft data. 2. Personnel in situ (diving team). 3. Improper performance of powertrain system.			0	1. Notice to maritime authorities if significant fragment broken off or diving incident. 2. Damage assessment. 3. Notice to insurance brokers, if significant damages.	
2	Powertrain system works inadequately	1. Performance under abnormal conditions.	Damage to assets			0	Mitigate	1. Inspection and maintenance at regular intervals. 2. Monitoring its performance from HMI.	1. Warning in HMI. 2. Personnel in situ, if any.			0	1. Consider actions to safeguard platform equipment, e.g. initiate shutdown/disconnection of device. 2. Corrective maintenance. 3. Heightened monitoring of the device.	
3	Rotor blades and powertrain spin at an excessive speed	1. Excessive tidal current. 2. Failure in generator	Damage to assets			0	Mitigate Transfer	1. Current meter installed. 2. Met mast installed. 3. Variable blade pitch system. 4. Insurance for Property Damage and Third Party Liability in place.	1. Warning in HMI.			0	1. Full-feathering blades. 2. Heightened monitoring of the device. 3. Corrective maintenance, if necessary.	
4	Power transformer works inadequately	1. Faulty power transformer. 2. Failure in cable connections.	Damage to assets			0	Mitigate Transfer	1. Inspection and maintenance at regular intervals. 2. Monitoring its performance from HMI. 3. Insurance for Property Damage and Third Party Liability in place.	1. Warning in HMI. 2. Personnel in situ, if any.			0	1. Consider actions to safeguard platform equipment, e.g. initiate shutdown/disconnection of device. 2. Corrective maintenance. 3. Heightened monitoring of the device.	
5	Failure in mooring system	1. Faulty elements comprising the mooring system. 2. Unappropriate installation of mooring system. 3. Loads exceeding design load.	Damage to assets			0	Mitigate Transfer	1. Check all components before their installations. 2. Use and install certified equipment/components. 3. Installation by company experienced in marine operations. 4. Heightened monitoring in adverse weather conditions. 5. Insurance for Property Damage and Third Party Liability in place.	1. Personnel in situ, during mooring system installation. 2. Data from met mast. 3. Data from current meter. 4. Data fom GPS. 5. Data from IMU. 6. Other warnings in HMI. 7. Data from dinamometer in mooring lines.			0	1. Consider actions to safeguard platform equipment, e.g. initiate shutdown/disconnection of device. 2. Notice to EMEC 3. Notice to maritime authorities. 4. Notice marine operations company for rapid response, if required. 5. ERP. 6. Heightened monitoring of the device. 7. Consider arranging mooring inspection by diver or ROV. 8. Notice to insurance brokers.	
6	Loads exceeding mooring design loads during turbine operation	1. Wind speed higher than XXX knots.	Damage to assets			0	Mitigate Transfer	1. Full-feathering blades. 2. Heightened monitoring in adverse weather conditions. 3. Insurance for Property Damage and Third Party Liability in place.	1. Met mast data. 2. Data from weather station onshore. 3. Data from Governmental Met Office. 4. Data from dinamometer in mooring lines.			0	1. Consider actions to safeguard platform equipment, e.g. initiate shutdown/disconnection of device. 2. Heightened monitoring of the device. 3. Notice to marine operations company for rapid response, if required.	
7	Loads exceeding mooring design loads during turbine operation	1. Waves higher than XXX	Damage to assets			0	Mitigate Transfer	1. Full-feathering blades. 2. Heightened monitoring in adverse weather conditions. 3. Insurance for Property Damage and Third Party Liability in place.	1. Data from EMEC wave buoy. 2. Data from Governmental Met Office. 3. Data from IMU. 4. Data from dinamometer in mooring lines.			0	1. Consider actions to safeguard platform equipment, e.g. initiate shutdown/disconnection of device. 2. Heightened monitoring of the device. 3. Notice to marine operations company for rapid response, if required.	
8	Loads exceeding mooring design loads during turbine operation	1. Speed current greater than XXX	Damage to assets			0	Mitigate Transfer	1. Full-feathering blades. 2. Heightened monitoring in adverse weather conditions. 3. Insurance for Property Damage and Third Party Liability in place.	1. Data from current meter. 2. Data from EMEC ADCP. 3. Data from dinamometer in mooring lines.			0	1. Consider actions to safeguard platform equipment, e.g. initiate shutdown/disconnection of device. 2. Heightened monitoring of the device. 3. Notice to marine operations company for rapid response, if required.	
9	Loads exceeding mooring design loads during turbine operation	1. Waves higher than XXX and speed current greater than XXX	Damage to assets			0	Mitigate Transfer	1. Full-feathering blades and resistive torque in generator. 2. Heightened monitoring in adverse weather conditions. 3. Insurance for Property Damage and Third Party Liability in place.	1. Met mast data. 2. Data from weather station onshore. 3. Data from EMEC wave buoy. 4. Data from IMU. 5. Data from current meter. 6. Data from EMEC ADCP. 7. Data from Governmental Met Office. 8. Data from dinamometer in mooring lines.			0	1. Consider actions to safeguard platform equipment, e.g. initiate shutdown/disconnection of device. 2. Heightened monitoring of the device. 3. Notice to marine operations company for rapid response, if required.	

Risk Id.	Risk Description	Cause of Risk	Consequence of Risk	Prob (1-4)	Impact (1-4)	Risk Score	Risk Response Type	Risk Prevention Measure Description	Risk Trigger	Prob (1-4)	Impact (1-4)	Risk Score	Response if risk becomes an issue	Risk Owner
10	Loads exceeding mooring design loads during turbine operation - & communication with control centre doesn't work	1. Waves higher than XXX and speed current greater than XXX	Damage to assets			0	Mitigate Transfer	1. Full-feathering blades and resistive torque in generator controlled automatically by PLC. 2. Heightened monitoring in adverse weather conditions. 3. Insurance for Property Damage and Third Party Liability in place.	1. No data available in HMI. 2. Data from weather station onshore. 3. Data from EMEC wave buoy. 4. Data from EMEC ADCP. 5. Data from Governmental Met Office. 6. Data from dinamometer in mooring lines.			0	1. Consider actions to safeguard platform equipment, e.g. initiate shutdown/disconnection of device. 2. Heightened monitoring of the device. 3. Notice to marine operations company for rapid response, if required. 4. Notice to EMEC. 5. ERP. 6. Corrective maintenance.	
11	Loads exceeding mooring design loads during turbine operation - & variable blade pitch system doesn't work	1. Waves higher than XXX and speed current greater than XXX	Damage to assets			0	Mitigate Transfer	1. Braking system. 2. Heightened monitoring in adverse weather conditions. 3. Insurance for Property Damage and Third Party Liability in place.	1. Met mast data. 2. Data from weather station onshore. 3. Data from EMEC wave buoy. 4. Data from IMU. 5. Data from current meter. 6. Data from EMEC ADCP. 7. Data from Governmental Met Office. 8. Warning in HMI about variable blade pitch system. 9. Data from dinamometer in mooring lines.			0	1. Consider actions to safeguard platform equipment, e.g. initiate shutdown/disconnection of device. 2. Heightened monitoring of the device. 3. Notice to marine operations company for rapid response, if required. 4. Notice to EMEC. 5. ERP. 6. Corrective maintenance.	
12	Loads exceeding mooring design loads during turbine operation - & variable blade pitch system doesn't work - & braking system doesn't work	1. Waves higher than XXX and speed current greater than XXX	Damage to assets			0	Mitigate Transfer	1. Break of elastic coupling. 2. Heightened monitoring in adverse weather conditions. 3. Insurance for Property Damage and Third Party Liability in place.	1. Met mast data. 2. Data from weather station onshore. 3. Data from EMEC wave buoy. 4. Data from IMU. 5. Data from current meter. 6. Data from EMEC ADCP. 7. Data from Governmental Met Office. 8. Warning in HMI about variable blade pitch system. 9. Warning in HMI about braking system. 10. Data from dinamometer in mooring lines.			0	1. Consider actions to safeguard platform equipment, e.g. initiate shutdown/disconnection of device. 2. Heightened monitoring of the device. 3. Notice to marine operations company for rapid response, if required. 4. Notice to EMEC. 5. ERP. 6. Corrective maintenance.	
13	Subsea cable connector is dragged on the sea bed.	1. Platform coming off the moorings.	Damage to assets			0	Mitigate Transfer	1. Fast umbilical connection on upper deck, which disconnects when a certain stress in the cable is achieved. 2. Insurance for Property Damage and Third Party Liability in place.	1. Data from GPS. 2. Failure in power grid supply.			0	1. Consider actions to safeguard platform equipment, e.g. initiate shutdown/disconnection of device. 2. Notice to EMEC. 3, Notice to marine operations company for rapid response. 4. ERP. 5. Consider arranging inspection by diver or ROV. 6. Notice to insurance brokers.	
18	Struck by moving object	1. Platform under towing tests. 2. Unsecured objects moving.	Damage to assets Injury			0	Mitigate Transfer	1. Personal Protective Equipment. 2. Secure loose objects. 3. Inspection of bearing structures. 4. First-aid equipment in place. 5. Insurance for Property Damage and Third Party Liability in place.	1. Personnel in situ.			0	1. Treat injuries. 2. If unable to treat injury, liaise as required with Emergency services. 3. ERP. 4. Damage assessment. 5. Notice to insurance brokers.	

APPENDIX G – PROVISIONAL UMBILICAL ARRANGEMENT

14.5 SUMMARY

Described below is a brief summary of the umbilical arrangement.

This arrangement is provisional.

Due to the nature of the mooring loads and the size of the chain and components, this arrangement will have not influence on the mooring loads or mooring design. However, clearance of the umbilical, to prevent damage to the umbilical needs to be assessed.

14.6 UMBILICAL SYSTEM CONFIGURATION – BASIS OF DESIGN

The following are the principle characteristics and requirements of the umbilical connection system:

- **Lazy Wave Configuration** - To ensure that the minimum bend radius and the safe allowed tension of the cable are exceeded, a lazy wave configuration will be designed where additional slack in the cable will be suspended above the sea floor. Some buoyancy and additional weight in the cable may be applied to achieve this.
- **Device Interface Protection –** It is advised to fit a J-tube to tidal platform offering protection and guidance of the cable as it leaves the device.
- **Bend Protection –** Within each point of the system adequate protection must be in place to avoid the minimum bend radius of the cable being exceeded.

14.7 DEVICE INTERFACE

The device interface sees the connection of the dynamic cable to the Tidal Platform. Figure 0-1 illustrates a schematic of this area.

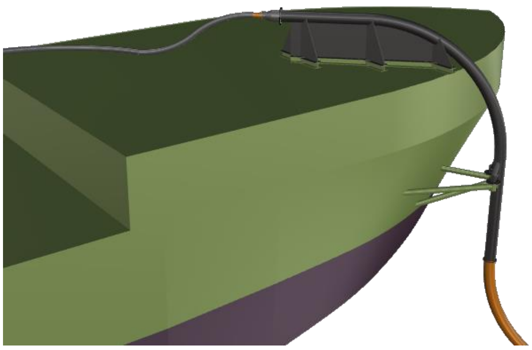


Figure 0-1 - Device Interface with tidal platform

- Summary of requirements are as follows:
- Guidance of cable as it is fed from the arch;
- Protection of cable as it is connected to the device;
- Attachment points to the secure cable.

The attachment point is mounted to the starboard side of the device where the cable will be brought across the device to the cable entrance point on the port side of the platform. A plan view of the dynamic cable layout is shown in Figure 2-4 which illustrates the design reasoning behind the starboard side mounting.

14.8 SYSTEM DESIGN

14.8.1 OVERVIEW

A schematic of the device interface is shown in Figure 0-2.

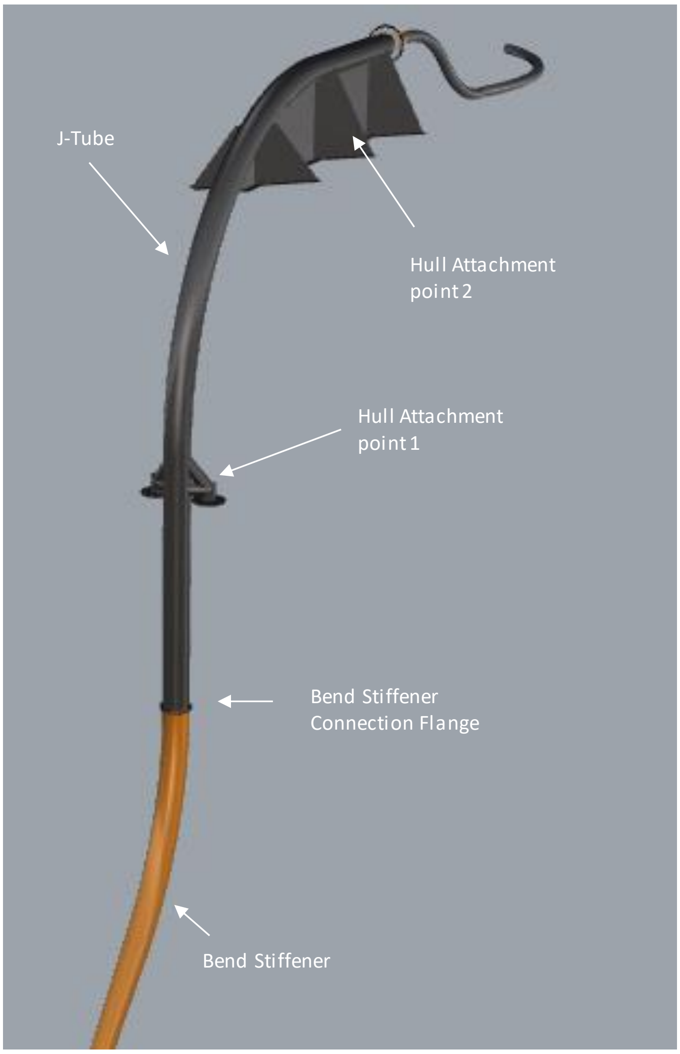


Figure 0-2 - Device Interface

The cable enters the interface through a bend stiffener, this is to ensure that the minimum bend radius of the cable is not infringed.

The bend stiffener is connected to the main body of the J-tube through a simple flange design.

The main body of the interface is form by the J-tube which takes the cable through the splash zone on to the deck of the Tidal Platform.

A cable terminated joint finishes the arrangement allowing the armour to protect of the cable to be removed and thus allow the cable to be connected directly into the device.

The interface is attached to the Tidal Platform through two separate attachment points.

14.9 LOADS

The following is an extract used for structural design purposes. The attachment point must be designed to withstand both static and dynamic environmental forces.

The static forces can be summaries as

- Weight of J-tube
- Weight of Cable

The dynamic Force can be summaries as

- Drag force
- Excursion force

The dynamic forces are calculation as a function of mainly surface area and tidal velocity. But it is important to note that these dynamic forces will be accelerated with the roll and pitch of the tidal platform as both the platform and the current will have a relative velocity to each other.

At each of the tow hull attachment points there will be 6 degrees of freedom and hence there will be 6 separate reaction forces. This given 12 forces in total across the two hull attachment points. These forces are summaries schematically in Figure 0-3, Figure 0-4 and Figure 0-5.

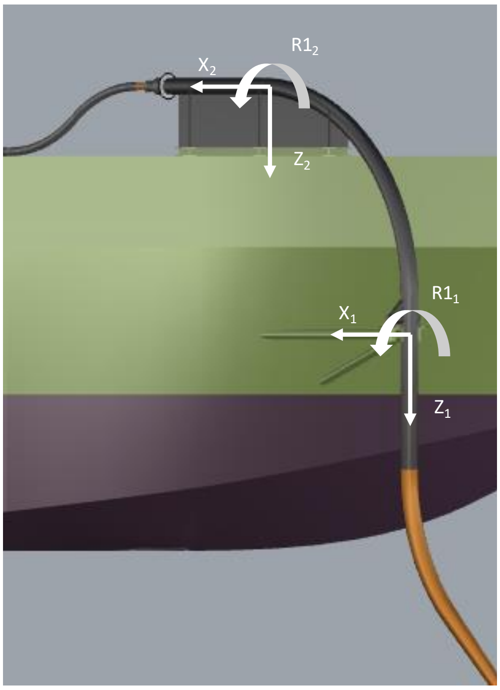


Figure 0-3 - Force Convention 1

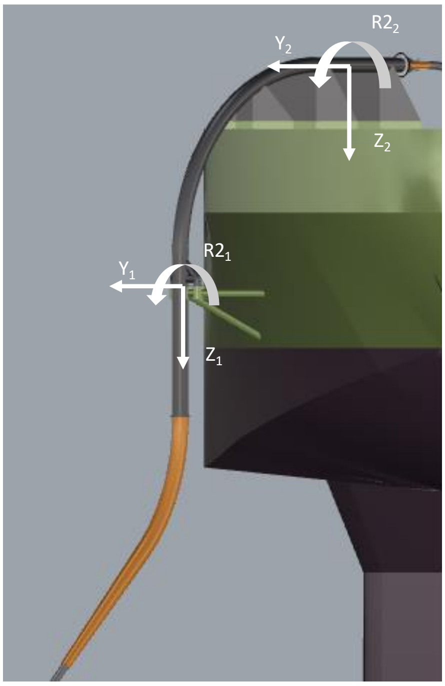


Figure 0-4 - Force Conventions 2

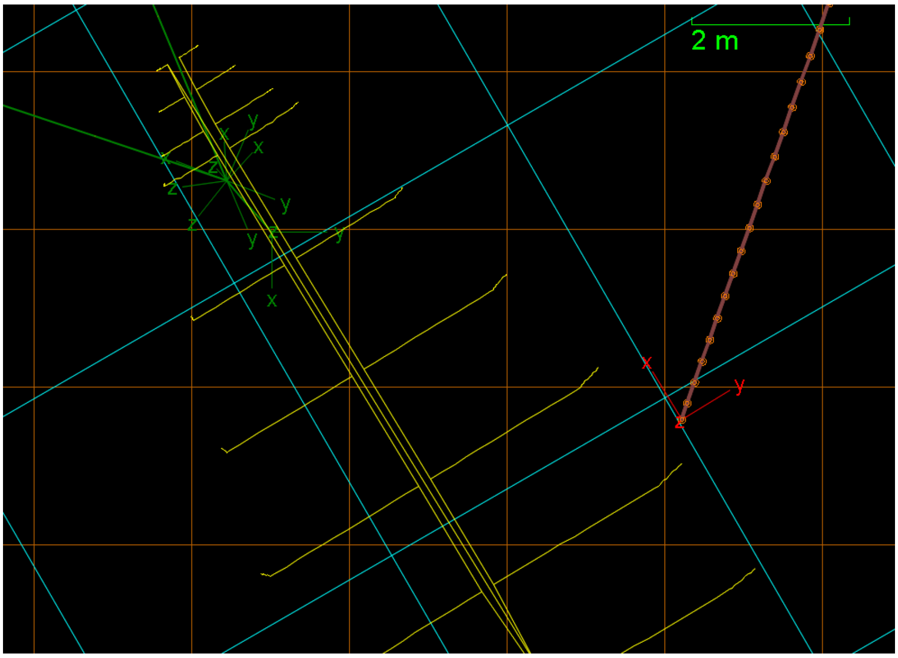


Figure 0-5 - Force Conventions 3

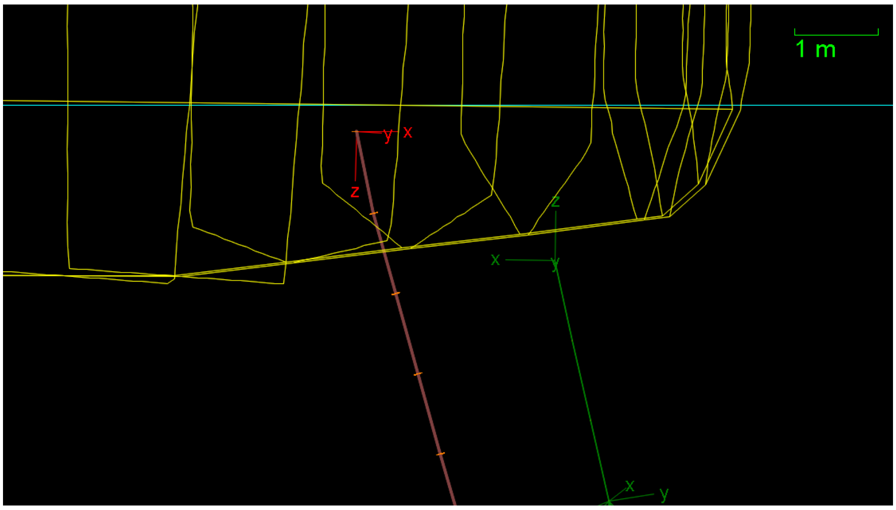


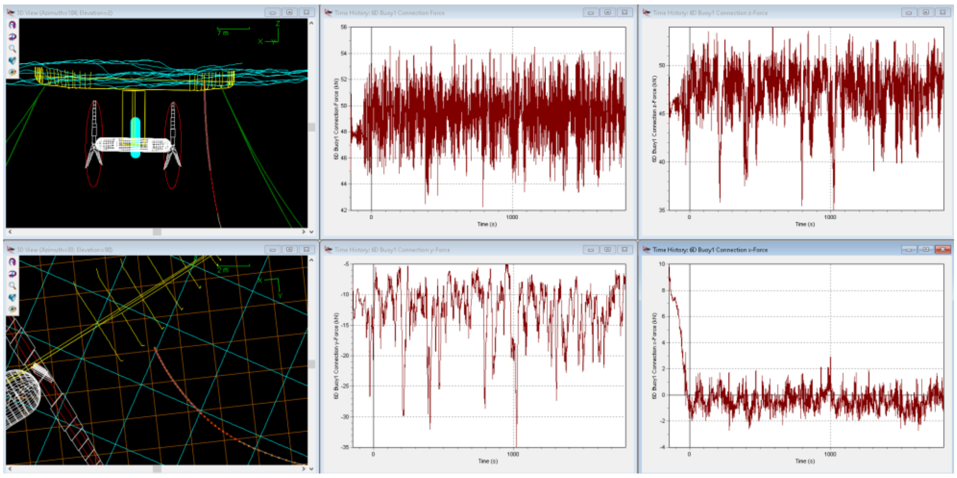
Figure 0-6 - Force Conventions 3

14.10 FORCES

Following dynamic simulations in Flood and Ebb tides the following presents indicative loads for preliminary structural design.

TIDE	VERTICAL FORCE Factored by 1.5	SHEAR / X FORCE Factored by 1.5	SHEAR / Y FORCE Factored by 1.5
FLOOD	81.6KN (54.4)	5.25KN(3.52)	66KN(44.63)
EBB	71.6KN (47.7)	44.7KN (29.8)	21.8KN(14.53)

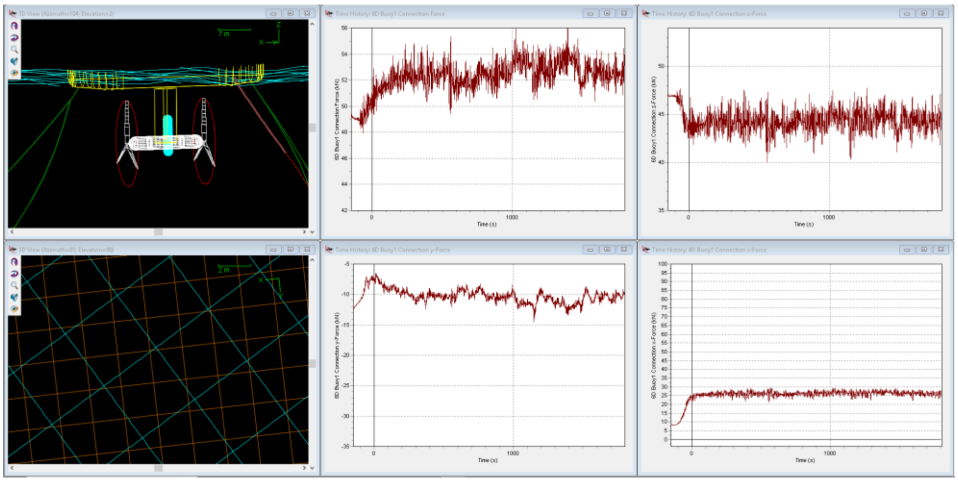
Table 0-1 - Factored loads to be used for design purposes. The value in brackets is the actual value taken from Figure 0-7 and Figure 0-8



OrcaFlex 10.2a: MAGALLANES_110218_FLOOD.sim (modified 1:27 PM on 12-Feb-18 by OrcaFlex 10.2a)

Variable	Period (s) From	To	Minimum	Time	Maximum	Time	Mean	Std. Dev.
Connection Force (kN)	-150.00	0.00	44.66	-29.60	53.22	-3.40	48.12	1.54
	0.00	2878.40	41.49	2707.10	55.07	587.60	49.31	2.04
Connection x-Force (kN)	-150.00	0.00	-1.75	-5.80	9.76	-146.70	4.56	3.19
	0.00	2878.40	-3.52	2744.70	3.33	2710.00	-0.42	0.76
Connection y-Force (kN)	-150.00	0.00	-26.71	-27.20	-7.95	-149.50	-13.16	3.39
	0.00	2878.40	-44.63	2721.80	-3.66	955.60	-12.90	5.22
Connection z-Force (kN)	-150.00	0.00	39.72	-29.40	51.09	-14.90	45.82	1.71
	0.00	2878.40	18.34	2720.10	54.44	587.60	47.23	3.24

Figure 0-7 - FLOOD - Time history of loads in cable at device end



OrcaFlex 10.2a: MAGALLANES_110218_EBB.sim (modified 1:26 PM on 12-Feb-18 by OrcaFlex 10.2a)

Variable	Period (s) From	To	Minimum	Time	Maximum	Time	Mean	Std. Dev.
Connection Force (kN)	-150.00	0.00	47.93	-65.50	51.21	-0.30	49.39	0.66
	0.00	2220.08	49.38	11.00	56.00	1025.00	52.49	0.91
Connection x-Force (kN)	-150.00	0.00	8.10	-128.40	25.35	-14.70	14.21	5.97
	0.00	2220.08	21.22	554.00	29.80	1975.80	26.19	1.24
Connection y-Force (kN)	-150.00	0.00	-12.30	-146.40	-6.92	-13.50	-9.58	1.80
	0.00	2220.08	-14.53	1148.50	-6.55	11.90	-10.37	0.99
Connection z-Force (kN)	-150.00	0.00	42.51	-8.30	47.72	-61.00	45.89	1.37
	0.00	2220.08	40.05	557.00	47.77	1268.30	44.26	1.06

Figure 0-8 - EBB - Time history of loads in cable at device end

APPENDIX H – EQUIVALENT YAW CALCULATION OF RECTANGULAR BOX

6D Buoys: Hydrodynamic Properties of a Rectangular Box

Lumped buoys are generalised six degree of freedom objects with indeterminate geometry: only their height is defined. It is therefore necessary to define their hydrodynamic properties such as inertia, drag area, and added mass explicitly as data items. This can be a difficult task, especially where the buoy is used to represent a complex shape such as a midwater arch of the sort used to support a flexible riser system.

We cannot give a universal step-by-step procedure for this, given the widely-varying geometry of different objects. Instead we provide, as an example, the derivation of the hydrodynamic properties in 6 degrees of freedom for a rectangular box. This gives a general indication of the way in which the problem may be approached.

The same analysis applies to 3D buoys, since they likewise have no defined geometry. In this case, however, the rotational properties are not required.

Drag Areas

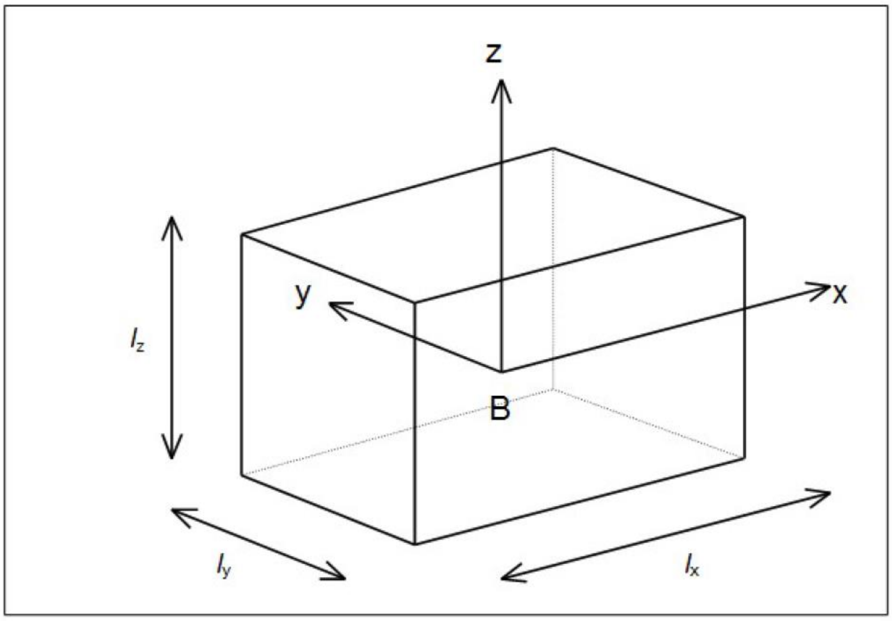


Figure: Rectangular box geometry

The drag areas are given by

$$A_x = l_y l_z \text{ in the } x \text{ direction}$$
$$A_y = l_x l_z \text{ in the } y \text{ direction}$$
$$A_z = l_x l_y \text{ in the } z \text{ direction}$$

Drag Coefficients for Translational Motions

These are obtained from ESDU 71016, Figure 1, which gives data for the drag on isolated rectangular blocks with one face normal to the flow. The dimensions of the block are a in the flow direction, b and c normal to the flow with $c>b$.

Their figure plots drag coefficient C_x against (a/b) for discrete values of (c/b) from 1 to infinity. C_x is in the range 0.9 to 2.75 for blocks with square corners.

Note: *ESDU 71016 uses C_d for the force in the flow direction; C_x for the force normal to the face. For present purposes the two are identical.*

Drag Properties for Rotational Motions

There is no standard data source. As an approximation, we assume that the drag force contribution df from an elementary area dA is given by

$$\mathrm{d}f = \frac{1}{2}\rho\,|\boldsymbol{v}|^2 C_\mathrm{d}\,\mathrm{d}A \tag{1}$$

where C_d is assumed to be the same for all points on the surface.

Note: *This assumption is not strictly valid. ESDU 71016 gives pressure distributions for sample blocks in uniform flow which show that the pressure is greatest at the centre and least at the edges, but we do not allow for this here.*

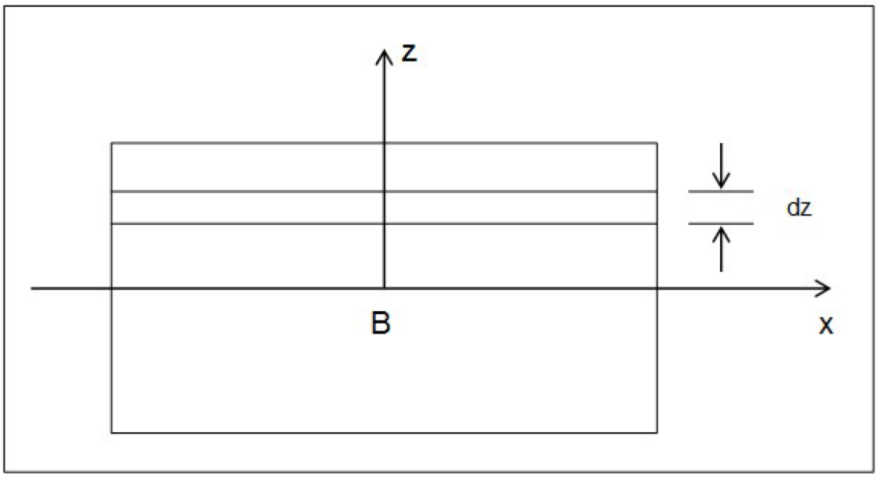


Figure: Integration for rotational drag properties

Consider the box rotating about the Bx axis. The areas A_y and A_z will attract drag forces which will result in moments about Bx . For the area A_y , consider an elementary strip as shown. For an angular velocity ω about Bx , the drag force on the strip is

$$\mathrm{d}f = \frac{1}{2}\rho\,\omega z\,|\omega z| C_\mathrm{d}\,x\,\mathrm{d}z \tag{2}$$

and the moment of this force about Bx is

$$\mathrm{d}m = \frac{1}{2}\rho\,\omega z\,|\omega z| C_\mathrm{d}\,x\,\mathrm{d}z\,z \tag{3}$$

$$= \frac{1}{2}\rho\,\omega\,|\omega| C_\mathrm{d}\,x\,z^3\,\mathrm{d}z \tag{4}$$

Total moment m is then obtained by integration. Due to the $v|v|$ form of the drag force, simple integration from -Z/2 to +Z/2 gives $m{=}0$, so we integrate from 0 to $z/2$ and double, resulting in

$$m = \frac{1}{2}\rho\,\omega|\omega| C_\mathrm{d}\,\frac{xz^4}{32} \tag{5}$$

OrcaFlex calculates the drag moment by

$$m = \frac{1}{2}\rho\,\omega|\omega| C_\mathrm{d,m}\,A_\mathrm{m} \tag{6}$$

where $C_\mathrm{d,m}$ and A_m are the drag coefficient and moment of area respectively, so we set

$$C_\mathrm{d,m} = C_\mathrm{d} \tag{7}$$

$$A_\mathrm{m} = \frac{xz^4}{32} \tag{8}$$

This is the drag moment contribution about Bx from the A_y area; there is a similar corresponding contribution from the A_z area. Since C_d generally differs for the two, it is convenient to calculate the sum of the $(C_\mathrm{d}\,A_\mathrm{m})$ products for both and then simply set A_m to this value and C_d to 1.

Added Mass

OrcaFlex requires the added mass and inertia contributions to the mass matrix, plus the hydrodynamic mass and inertia values to be used for computation of wave forces. For each of the six degrees of freedom, three data items are required: hydrodynamic mass HM (or inertia HI) and coefficients C_a and C_m . Added mass is then calculated as $AM = HM\,C_\mathrm{a}$ and wave force as $HM\,C_\mathrm{m}\,a_\mathrm{f}$ for water particle acceleration a_f .

On the usual assumptions intrinsic in the use of Morison's equation (that the body is small by comparison with the wavelength), the wave force is given by $(\Delta + AM)a_\mathrm{f}$, where Δ is body displacement. Equating the two expressions for wave force, we get

$$HM\,C_\mathrm{m}\,a_\mathrm{f} = (\Delta + AM)a_\mathrm{f} \tag{9}$$

For translational degrees of freedom then, set $HM = \Delta$, and it follows that $C_\mathrm{a} = AM/\Delta$ and $C_\mathrm{m} = 1{+}C_\mathrm{a}$ .For rotational degrees of freedom, set $HI = \Delta I$, the moment of inertia of the displaced mass, then $C_\mathrm{a} = AI/\Delta I$ and, again, $C_\mathrm{m} = 1{+}C_\mathrm{a}$. AI is the added inertia, the rotational analogue of added mass.

Translational Motion

DNV-RP-C205, Table 6.2, gives added mass data for a square section prism accelerating along its axis. The square section sides are of length a , prism length is b , and data are given for discrete values of $b/a = 1.0$ and above. The reference volume is the volume of the body, which corresponds to our own definition in OrcaFlex. We can therefore use the calculated C_{a} without further adjustment.

Consider flow in the x direction:

The area normal to the flow $= A_{\mathrm{x}}$.

For a square of the same area, $a = \sqrt{A_{\mathrm{x}}}$

Length in flow direction $= l_{\mathrm{x}}$.

Hence $b/a = l_{\mathrm{x}}/\sqrt{A_{\mathrm{x}}}$.

C_{a} can thus be obtained from DNV-RP-C205 by interpolation, and then $C_{\mathrm{m}} = 1{+}C_{\mathrm{a}}$.

If $b/a < 1$ this approach fails and we instead use the data given in DNV-RP-C205 for rectangular flat plates. If $l_{\mathrm{y}} > z$, the aspect ratio of the plate is $l_{\mathrm{y}}/l_{\mathrm{z}}$, and hence CA from DNV-RP-C205 by interpolation. The reference volume in this case is that of a cylinder of diameter l_{z} , length l_{y} , and so

$$\text{added mass} = CA\,\rho\,\frac{\pi}{4} y\,z^2 = AM_{\mathrm{x}}\ \text{say} \tag{10}$$

and then

$$C_{\mathrm{a}} = \frac{AM_{\mathrm{x}}}{\Delta} \tag{11}$$

$$C_{\mathrm{m}} = 1 + C_{\mathrm{a}} \tag{12}$$

Note: *If $y<z$, then aspect ratio $= z/y$ and reference volume $= CA\,\rho\frac{\pi}{4} z\,y^2$.*

Rotational Motion

DNV-RP-C205 gives no data for hydrodynamic inertia of rotating bodies. The only data for 3D solids we are aware of are for spheroids: figure 4.8 of Newman 1977 gives the added inertia for coefficient for spheroids of varying aspect ratio, referred to the moment of inertia of the displaced mass. We assume that the same coefficient applies to the moment of inertia of the displaced mass of the rectangular block.

Rotation about X

$$\Delta I = \Delta(Y^2 + Z^2)/12 \tag{13}$$

Added inertia

Using data for spheroids from Newman 1977,

Length in flow direction $= 2a = l_{\mathrm{x}}$, so $a = l_{\mathrm{x}}/2$.

Equivalent radius normal to flow, b , is given by $\pi b^2 = l_{\mathrm{y}} l_{\mathrm{z}}$, so $b = \sqrt{l_{\mathrm{y}} l_{\mathrm{z}}/\pi}$.

Hence Ca from Newman 1977:

For $b/a \le 1.6$, C_{a} can be read from the upper figure where the value is referred to the moment of inertia of the displaced mass. In this case no further adjustment is required.

For $b/a > 1.6$, the coefficient CA is read from the lower graph in which the reference volume is the sphere of radius b . In this case,

$$C_a = CA \frac{2b^3}{a(a^2 + b^2)} \tag{14}$$

In either case, $C_m = 1 + C_a$.

APPENDIX I – DRAG TEST MEMO LSK-ENG-MEMO-180117

TECHNICAL NOTE

From:	Leask Marine	**Project:**	TIDAL TURBINE INSTALL
		Date:	18th January 2017
To:	Orcades Marine		
Cc:		**Memo No.**	LSK-ENG-MEMO-180117
Subject:	EMEC Mooring Clump Drag test		

1.1 Introduction

A tidal turbine device is to be installed at EMEC at the Fall of Warness. The device will require a 4 point mooring system. Each mooring leg is to be comprised of a chain clump weight, a length of heavy ground chain and a riser wire.

The weight of the chain clumps is a key design value and a project cost/feasibility driver.

The design criteria governing clump size is the coefficient of friction between the clump and seabed.

There are various codes and reputable firms specifying recommended friction coefficient values of between 0.8 and 1.0 for chain against seabed and between 0.3 and 0.7 for solid steel or concrete clump weights[1], but none that present a value for chain clumps. Therefore, despite informal experiences of higher values, a conservative choice has to be made based on these documented values.

A first issue of the design report for this tidal device asserted a value of 0.7. Comments from the TPV authority reviewing the mooring design asserted that a value of 0.6 should be used.

On the basis that the TPV assertion was overly conservative and would result in unnecessary increased project costs, a drag test was proposed to be performed using a 24t chain clump, in order to generate results sufficient to justify a friction coefficient of the mooring clump/ seabed interface in excess of 0.7.

The following is a summary of that experiment and the basis for the coefficient value recommended.

1.2 Executive Summary

Following the drag trials reported in this document it is proposed to use a friction coefficient value between chain clump weight and seabed of 0.8.

- [1] OS-E301 Section 2 Part B104 Recommends a coefficient of friction of 1.0 for chain to seabed contact. However, this assumes that the chain length is fully in contact with the seabed.
- BS6349, Part 6, Table 6 recommends a coefficient of friction for deadweight anchors (i.e. a concrete or steel clump) of 0.3 for silt and soft clay to 0.5 for sand and firm clay.
- Barge Mooring" Oilfield, Seamanship, Vol. 6, Hancox recommends a coefficient of friction for chain on rock as 0.8
- Informal tests in the Fall of Warness at EMEC using almost identical clump weight types have proven a coefficient in excess of 0.8 based on load tested anchor pull tests

1.3 Operations

Drag tests were planned to be performed at the actual site. However the weather on the day on site was aggressive with large swell which prevented satisfactorily constant load cell readings. The tests were therefore forced to a sheltered locations approximately 9km SW of EMEC Berth 8.

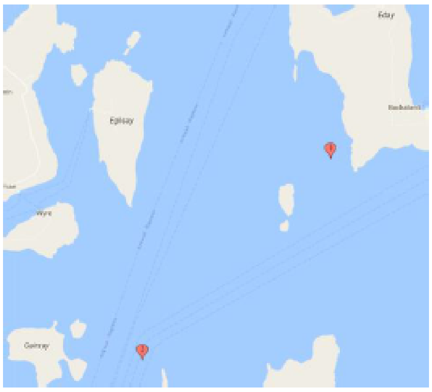


Figure 1 -Target position in the NE for the tests and actual position forced due to weather to the SW

- A camera survey was performed at relocation to more sheltered waters. This indicated that the seabed was reasonably level, partially sandy with small rocks on the surface.

- A 24t chain clump was deployed from the bow and a 34t clump deployed at a location approximately 190m Southeast.

- The bow mooring wire was prepared for load testing and the test began in the steps as per Section 1.4 below.

1.4 Methodology Steps

The following equipment was used in the experiment.

A storyboard is presented in Appendix B

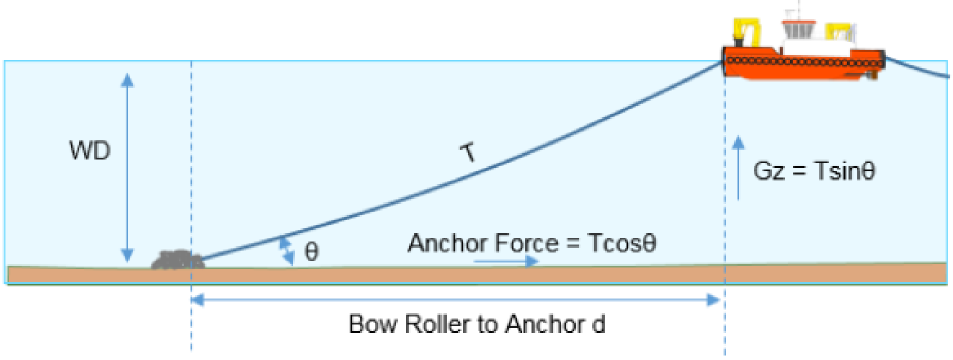
Equipment List	
Item	**Quantity**
24t Chain Clump (measured at 2..2t in water	1
34t Chain Clump	1
200m Mooring Wire (2 x 100m lengths)	1
100m Mooring Wire	1
Load Cell	1
Spyball Drop Camera	1

1. Pre-test camera survey of the new drag test location revealed that the seabed is mostly level and sandy with small rocks and shale at the surface
2. 24t Bow clump rigged to main winch and deployed at UTM 30 504925E, 6549099N
3. 34t Aft clump rigged to anchor winch and deployed at UTM 30 505020E, 6548967N (190m distance from 24t clump)
4. Vessel moved to central location between clumps
5. Load cell rigged to spelter socket at mid-point of bow mooring wire and towing pins then overboarded, load cell zeroed to eliminate weight of mooring wire from results
6. Anchor winch paid in to tension mooring lines, tension held for period of 3 minutes
7. Water depth and vessel position recorded, load cell reading recorded at 1 minutes increments from beginning of test
8. Anchor winch increased by approximately 1.0t
9. Step 7 repeated for increased loading
10. Steps 8 and 9 repeated until load cell readings indicate that the bow clump is being dragged
11. Upon reaching clump yield tension; load cell monitored whilst anchor winch pays in and drags clump weight, winch then held and loads recorded as per Step 9
12. Step 11 repeated twice to confirm anchor yield tension
13. Aft clump weigh recovered to deck
14. Post-test camera survey of Bow clump performed
15. Bow clump weighed by load cell and recovered to deck

1.5 Seabed Coefficient Calculation

- The following calculation was used for the calculation of the friction coefficient.
- Simplistically the angle was calculated between vessel and anchor and the resulting vertical load at the anchor calculated.
- The resulting clump weight (i.e the dead weight minus the GZ force) was calculated.
- The force at drag was derived from the experiment and the resulting coefficient derived.

$$Anchor\ Requirement = \frac{Anchor\ Force}{Seabed\ Friction\ Coefficient} + Gz\ Force$$



1.6 Seabed Coefficient Results Summary

The calculation of the yield friction coefficient is presented below.

Detailed results for all cases are presented in Appendix A.

Equipment List		
Item	**Unit**	**Value**
Avg. Water Depth (WD)	m	32
Avg. Dist. From bow roller to clump (d)	m	116
Mooring Wire Inclination (θ)	°	15.4
Tension T at clump yield	t	16.0
Anchor Force	t	15.4
Gz Force	t	4.2
Anchor Weight in Water (Load tested on site)	t	22.2
Calculated Seabed Friction Coefficient	-	0.85

1.7 Experimental Observations

- Throughout individual stages of the test the load readings tended to be highest when the initial load came on from the anchor winch.

- At tensions below 17t, the initial load would then vary very slightly (up to 1t) and remain fixed for the rest of the test with no requirement to adjust the winch. These small changes are assumed to be due to settlement of the clump and motions of the vessel. The low variation in load at these tension indicated that the clump was holding firm.

- At tensions above 17/18t the winch continually paid in. This continual pay in showed that, at this tension, the clump was being dragged. A further dropdown camera survey confirmed this later.

- When the clump dragged the tension would reduce to range of 15t – 16t indicating that the clump was capable of holding 16t without clump movement. Despite no movement at 16t, 16t is specified here as the yield value and the maximum friction coefficient of 0.85 developed.

1.8 Analytical Observations

The nature of an extreme load event and the implication of a drag event needs to be considered in the selection of a coefficient and the level of conservativeness.

- If a drag event could result in a major cable failure or cost implications to another party's property a conservative approach needs to be taken.
- If a drag event results in low impact in terms of excursion and load then a less conservative approach is required.

Figure 4 below shows a time history of an extreme environmental condition where there are spring tides with beam seas of Hs 1.8m. The peak unfactored load is around 47t.

Figure 5 shows that this load occurs over a few seconds and does not last nor re-occur within 30minutes of the storm, with the remaining loads below 45t.

Figure 6 shows a simulation in the same environment but there are three models within the same simulation:

- Model 1 – No drag of the South West Anchor
- Model 2 – 10m drag of the South West Anchor
- Model 3 – 20m drag of the South West Anchor

Figure 7 8 and 9 show the implication to load, which is not significant. It is more of a transfer from SW to SE. In terms of excursion the excursion is principally lateral and is unlikely to damage the umbilical.

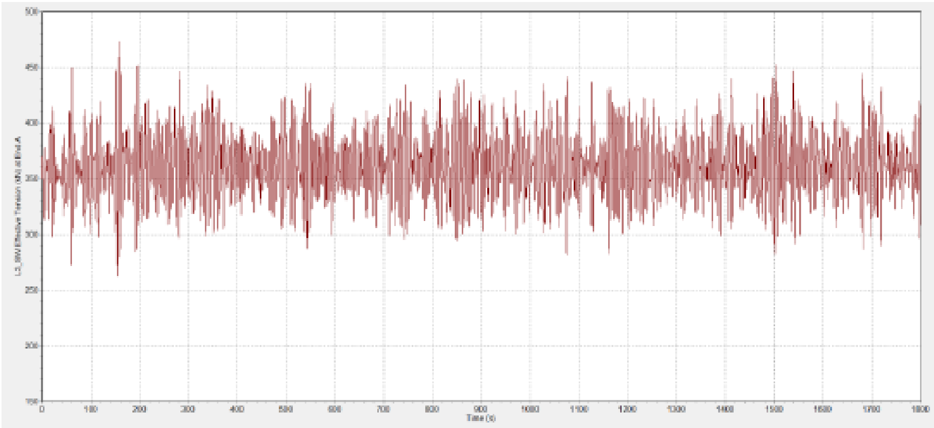


Figure 2 – 30 Minute Time History showing extreme anchor load

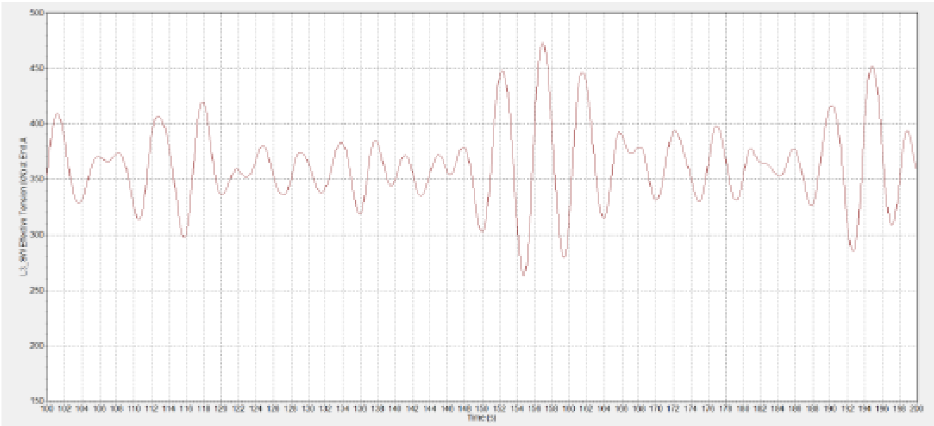


Figure 3 – 30 Minute Time History showing extreme anchor load

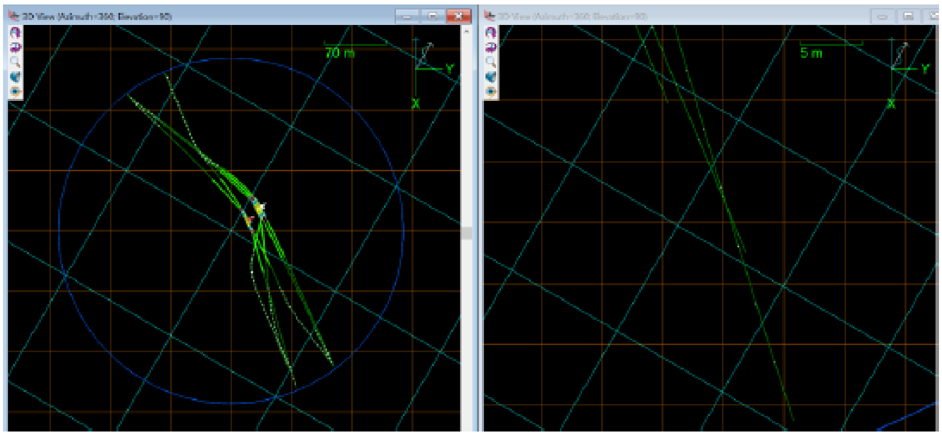


Figure 4 – Left – dynamic simulation showing increased excursion due to 0 Drag of SW anchor, 10m Drag of SW Anchor, 20m drag of SW anchor

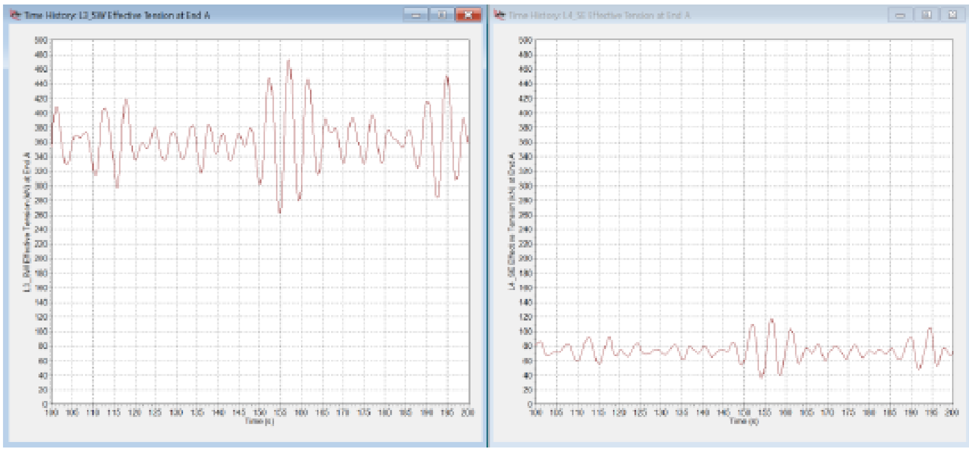


Figure 5 –0m Drag condition of SW clump, Left – SW unfactored load, Right SE unfactored load

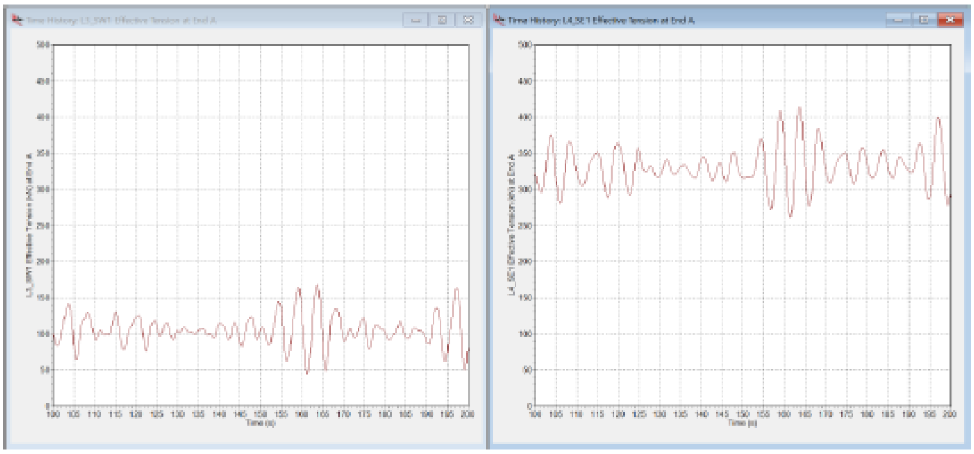


Figure 6 –10m Drag condition of SW clump, Left – SW unfactored load, Right SE unfactored load

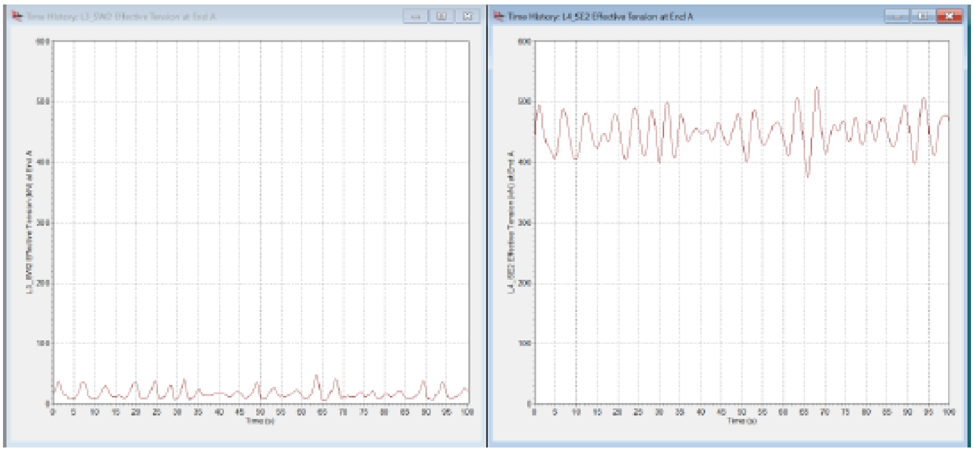


Figure 7 –20m Drag condition of SW clump, Left – SW unfactored load, Right SE unfactored load

1.9 Discussion

- The seabed at location 2 is of a sandy consistency whereas the seabed at EMEC Berth 8 has a rocky surface.

- DNV-RP-F109 discusses sand and concrete friction coefficient variations for pipelines in contact with seabed and asserts sand and rock as equal.

- Data from a reputable chain supplier Ramnas asserts chain friction coefficients to be higher on firm ground than sand. Vryhof and Global Maritime assert very similar coefficients for chain to seabed.

Coefficient of friction for anchor chain

The coefficient of friction depends upon the actual ocean bottom at the anchor location. General friction factors for chains are given in the table. The starting friction factors may be used to compute the holding power of the chain. The sliding friction factor may be used to compute forces on the chain during deployment.

Ocean bottom	Friction factors	
	Starting	Sliding
Sand	0.98	0.74
Mud with sand	0.92	0.69
Firm mud	1.01	0.62
Soft mud	0.90	0.56
Clay	1.25	0.81

Chain holding power generalized friction factors for mooring chain.

Figure 8 - Data from a RAMNAS chain catalogue

- Experiences by Leask Marine in the Fall of Warness and Meygen site where there is a predominantly rocky seabed has confirmed the benefits of a creviced rocky seabed for increased resistance of a chain clump compared with sandy seabed where there is less material resistance.

- Conversely, a counter argument could be asserted that on smooth rock there would be less sliding resistance than on sand or gravel seabed where the build-up of debris during a drag event may assist increased resistance.

- Analysis asserts that the consequence of a severe 20m drag event is of little consequence to the capacity of the system and on this basis, it is not necessary to take a highly conservative approach, by assuming cascade of events due to a drag event.

1.10 Conclusion

- It is recommended that a reduced value of 0.8 is selected instead of the proven 0.85 for use in the design calculations for the derivation of clump size.

- This decision for a reduction below 0.85 is asserted despite reputable arguments which assert the same or greater capacity in rocky seabed.

- There remains small uncertainty in the exact seabed properties at site compared to the test site.

- It is a deficiency in the testing that environmental conditions prevented testing at the actual site.

- A value lower than 0.8 is deemed to be overly conservative because of the short duration of the extreme load events, and the implication of a drag event being low with regards to excursion and increased load in the other mooring leg.

APPENDIX A – DETAILED RESULTS

Operation EMEC Berth 8 Seabed Drag Test
Client Tocardo
Supervisor O. Bethwaite
Personnel & Crew MF (Survey), DC (Rep), PR (Skipper), LO (Crew), GC(Crew)
Location Fall of Warness
Date 17/01/2017

LEASK MARINE

Methodology	
Stage 1 • Increase winch tension until load cell reads 10t • Hold tension for 4 mins. take readings at 2, 3, 4 minutes	• Record water depth and vessel position, take 1st load cell reading
Stage 2 • Increase tension back up to 10t and repeat process	Stage 3, 4 • Increase tension up to 11t and repeat processes for Stages 1 & 2
Stage 5+ • Increase tension in 1t increments and repeat Stages 1&2 until peak load is reached	• Repeat process 5 times for peak load

Clump Position	
Easting	Northing
5111238	6555852

Equipment
Load cell, 34t Stern Clump, 24t Bow Clump (measured by load cell at 22.2t in water)

Page Number 1

Stage	WD (m)	Vessel Position		Load cell Tension range		Comments
		Easting	Northing	No.	tonnes	
1	38.4	5111537	6555969	1.	5t - 13t	Load reading fluctuates too much for a reliable reading, test aborted
				2.		
				3.		Decision made to relocate test to more sheltered local area
				4.		

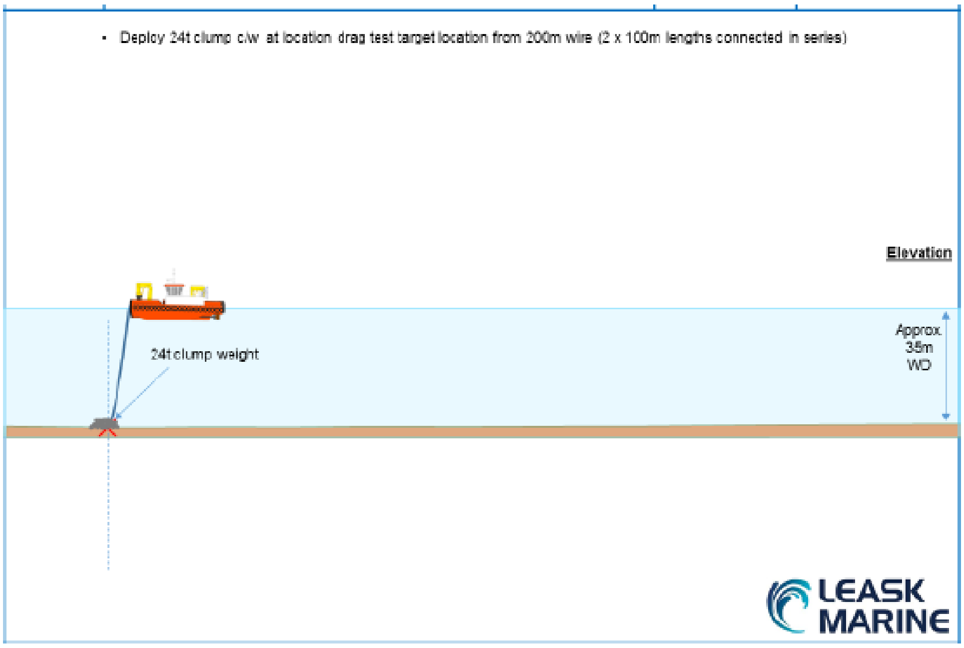
Clump Position	
Easting	Northing
504925	6549099

1	32.1	504990	6549009	1.	6.2 - 7.1	Load cell zeroed to account for line weight
				2.	6.4 - 7.5	
				3.	6.1 - 7.7	
				4.	7.1 - 8.5	
3	32.1	504990	6549010	1.	8.1 - 9.3	
				2.	8.0 - 9.9	
				3.	7.8 - 9.9	
				4.	9.6 - 10.7	
4	31.9	504990	6549010	1.	8.5 - 10.3	
				2.	8.1 - 9.8	
				3.	9.1 - 10.8	
				4.	9.6 - 10.7	

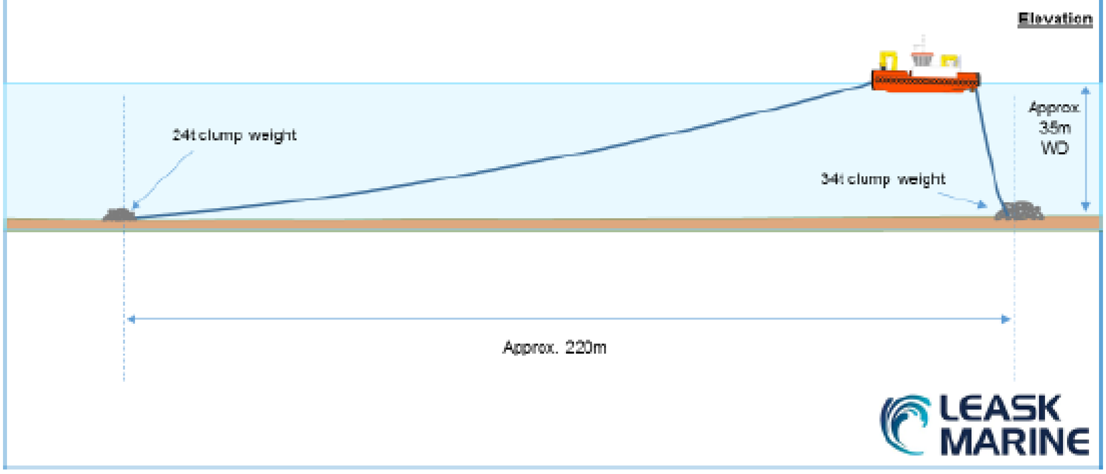
	Location			Date		Page Number
Stage	**WD (m)**	**Vessel Position**			**Load cell Tension**	**Comments**
		Easting	**Northing**	**No.**	**tonnes**	
5	32.1	504991	6549009	1.	9.8 - 11.2	
				2.	8.5 - 11.2	
				3.	8.5 - 11.3	
				4.	8.9 - 10.3	
6	32.3	504991	6549008	1.	10.6 - 11.6	
				2.	10.5 - 12.1	
				3.	9.6 - 10.5	
				4.	10.1 - 10.4	
7	32.3	504991	6549008	1.	11.5 - 12.4	Load dropped off after 12.4 peak; assumed that clumps still settling under tension
				2.	10.2 - 11.1	
				3.	9.4 - 10.1	
				4.	9.2 - 10.4	
8	32.3	504991	6549008	1.	10.8 - 12.8	Load dropped off after 12.8 peak; assumed that clumps still settling under tension
				2.	10.8 - 13.3	
				3.	10.6 - 13.0	
				4.	10.6 - 12.8	
9	32.1	504991	6549008	1.	10.5 - 11.6	Load spiked at 14.2 whilst tension was being ramped on
				2.	10.6 - 12.4	
				3.	10.4 - 12.5	
				4.	9.8 - 11.6	
10	32.3	504991	6549007	1.	10.6 - 13.1	
				2.	10.0 - 13.1	
				3.	11.4 - 13.4	
				4.	11.6 - 14.1	
11	32.3	504991	6549007	1.	13.1 - 14.7	Load spiked at 14.9 whilst tension was being ramped on Clump appears to be holding steady tension of 13t -14t
				2.	11.4 - 13.1	
				3.	11.3 - 14.1	
				4.	11.0 - 14.3	

	Location			Date		Page Number
Stage	**WD (m)**	**Vessel Position**			**Load cell Tension**	**Comments**
		Easting	**Northing**	**No.**	**tonnes**	
12	32.3	504991	6549007	1.	12.9 - 14	Load spiked at 15 whilst tension was being ramped on Clump appears to be holding steady tension of 13t -14t
				2.	12.6 - 14.2	
				3.	12.4 - 15.1	
				4.	11.8 - 13.2	
13	32.3	504991	6549006	1.	12.6 - 14.4	Load spiked at 16.2t
				2.	12.5 - 14.5	
				3.	12.1 - 15.2	
				4.	13.3 - 14.5	
14	32.3	504990	6549006	1.	11.9 - 14.5	Load spiked at 16.5t
				2.	12.3 - 15.3	
				3.	12.1 - 14.9	
				4.		
15	32.3	504990	6549006	1.	13.9 - 15.5	Most readings over 14t, clump likely holding at this tension
				2.	12.2 - 14.6	
				3.	12.5 - 16.2	
				4.	13.5 - 15.2	
16	32.3	504991	6549006	1.	13.0 - 16.7	16.7 Spike, holding at circa 15t
				2.	13.2 - 15.0	
				3.	13.4 - 16.1	
				4.	13.5 - 16.0	
17	32.3	504992	6549006	1.	13.9 - 16.6	17.0 Spike, holding at circa 15t
				2.	13.5 - 16.7	
				3.	14.2 - 16.3	
				4.	14.0 - 16.1	
18	32.3	504992	6549006	1.	14.7 - 17.4	17.8 Spike, holding at circa 16t
				2.	14.4 - 16.1	
				3.	14.5 - 16.6	
				4.	14.0 - 17.5	

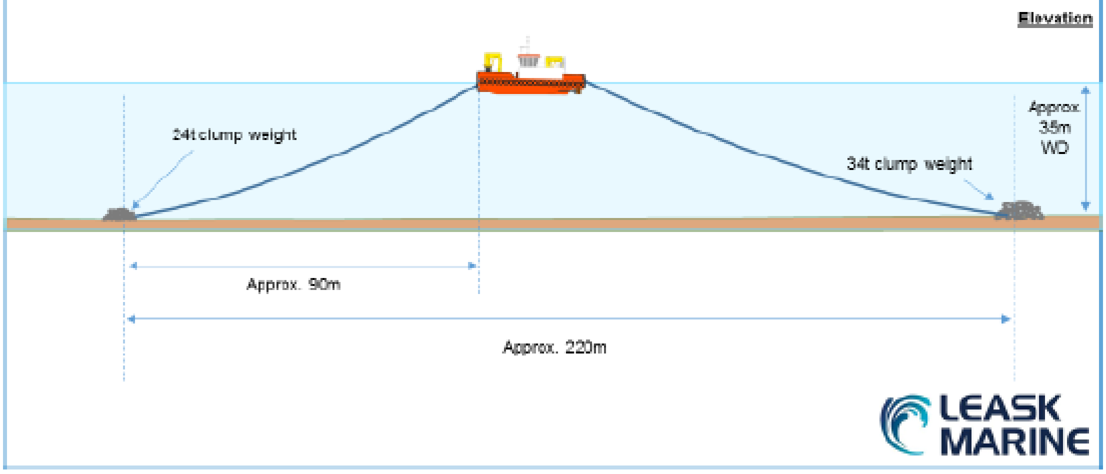
	Location			Date		Page Number
Stage	WD (m)	Vessel Position		Load cell Tension		Comments
		Easting	Northing	No.	tonnes	
19				1.	13.9 - 18.1	
				2.	14.2 - 15.8	
				3.	14.9 - 16.4	
	32.3	504991	6549006	4.	13.4 - 15.6	19.0 Spike, holding at circa 16t
20				1.	14.5 - 17.4	
				2.	14.1 - 16.0	
				3.	14.0 - 16.3	
	32.3	504992	6549006	4.	13.4 - 17.9	18.0 Spike Load dropped after initial peak down to 14t - 15t range
21				1.	14.8 - 17.1	
				2.	14.0 - 16.2	
				3.	15.0 - 16.5	
	32.3	504992	6549005	4.	15.5 16.7	19.0 Spike Dragging from 17t - 18t Settled at 15t - 16t
22				1.	14.6 - 18.4	
				2.	14.4 - 16.3	
				3.	14.0 - 16.2	
	32.3	504992	6549005	4.	14.2 - 16.9	19.4 Spike Dragging from 17t - 18t Settled at 15t - 16t



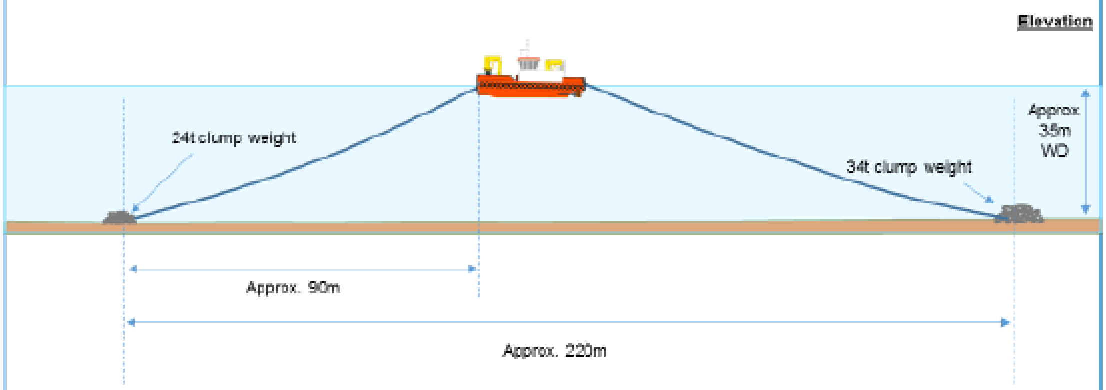
- Move vessel NE along TFS mooring leg route
- Deploy 34t clump weight from 100m wire



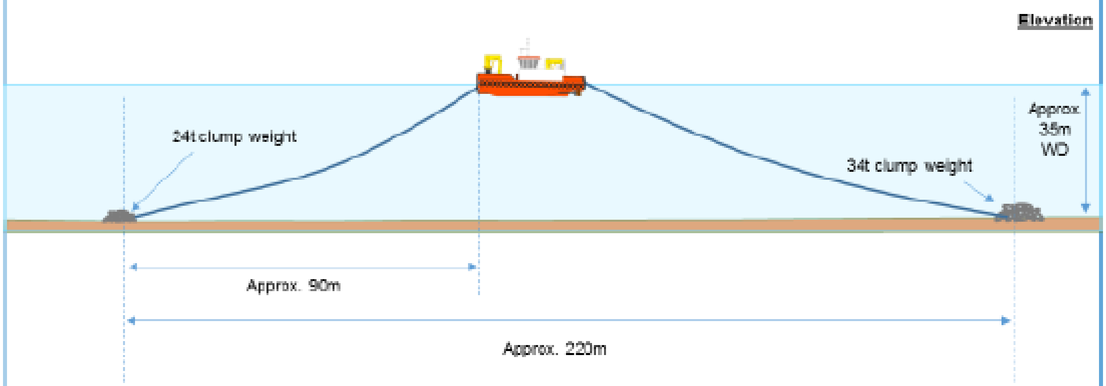
- Move vessel toward 24t clump and pay in on anchor winch until 200m wire central connection is recovered to deck
- Disconnect central connection and rig mooring wire & load cell to towing pins at bow
- Tension aft winch until both mooring lines are taut



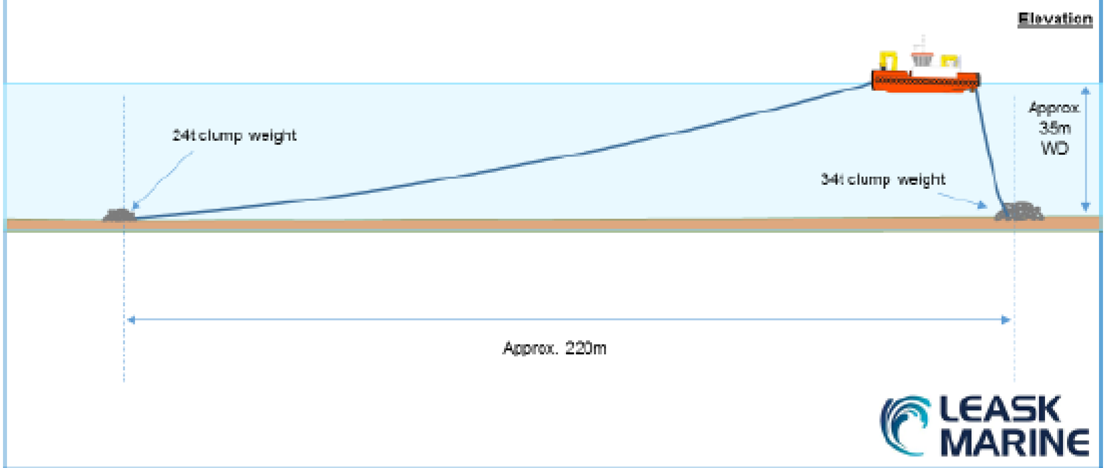
- Record water depth and vessel position/distance from 24t clump weight
- Begin incrementally tensioning aft winch until 24t clump weight yields
- This test to be conducted 5 times in total, all loads to be recorded in results table provided
- Record peak load cell reading



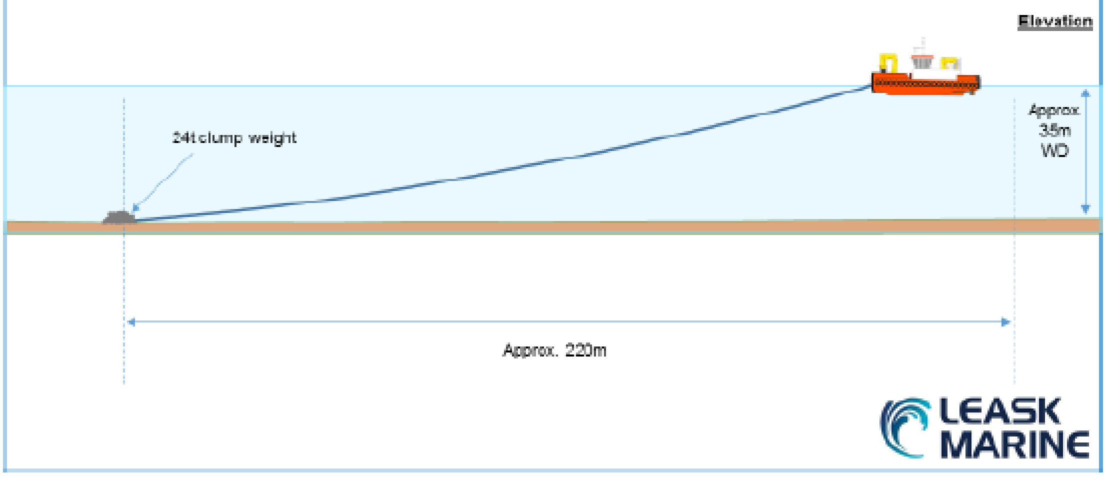
- Slacken aft winch
- Disconnect load cell from towing pins and reconnect 100m wire to clump wire and anchor winch



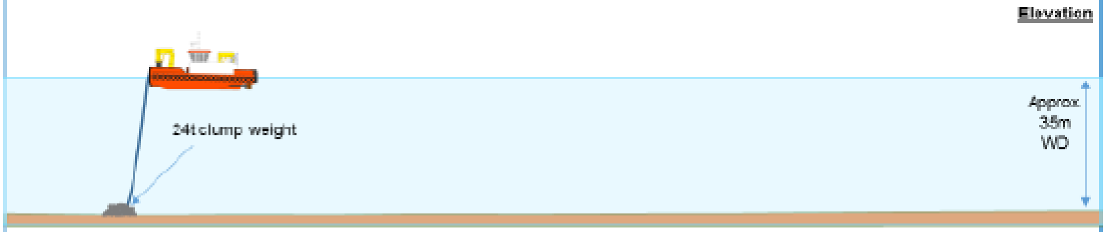
- Pay-out on anchor winch and move vessel toward 34t clump weight



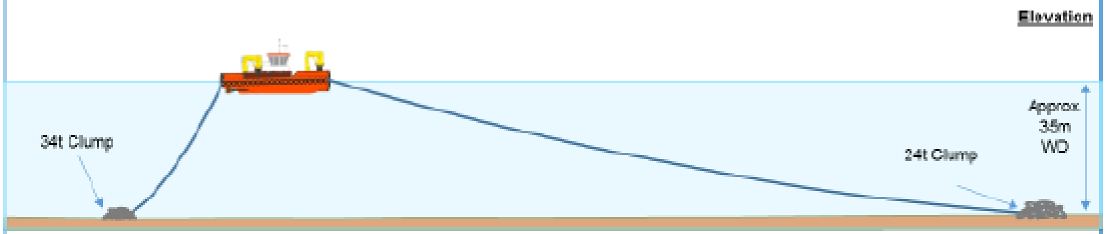
- Recover 34t clump weight



- Move vessel to 24t clump location
- Recover 24t clump weight



- Adjust rigging such that 34t clump mooring wire exits vessel over aft roller
- Begin moving vessel forward paying out on aft line and paying in on forward line



APPENDIX J – STABILITY ASSESSMENT

Default Project
Hydrostatics & Stability Analysis

Condition Summary

Load Condition Parameters

Condition	Weight / Sinkage	LCG / Trim	TCG / Heel	VCG (mm)
Condition 1	644200.000 kgf	0.000 deg	0.000 deg	-3280

Resulting Model Attitude and Hydrostatic Properties

Condition	Sinkage (mm)	Trim(deg)	Heel(deg)	Ax(m^2)
Condition 1	1945.308	0.000	0.000	22.54

Condition	Displacement Weight (kgf)	LCB(mm)	TCB(mm)	VCB(mm)	Wet Area (m^2)
Condition 1	644199.607	0.194	-0.006	-3005.930	665.277

Condition	Awp(m^2)	LCF(mm)	TCF(mm)	VCF(mm)
Condition 1	231.801	0.000	0.000	1945.308

Condition	BMt(mm)	BMl(mm)	GMt(mm)	GMl(mm)
Condition 1	1010.171	47256.419	1284.241	47530.489

Condition	Cb	Cp	Cwp	Cx	Cws	Cvp
Condition 1	0.157	0.645	0.894	0.243	4.039	0.175

Notes

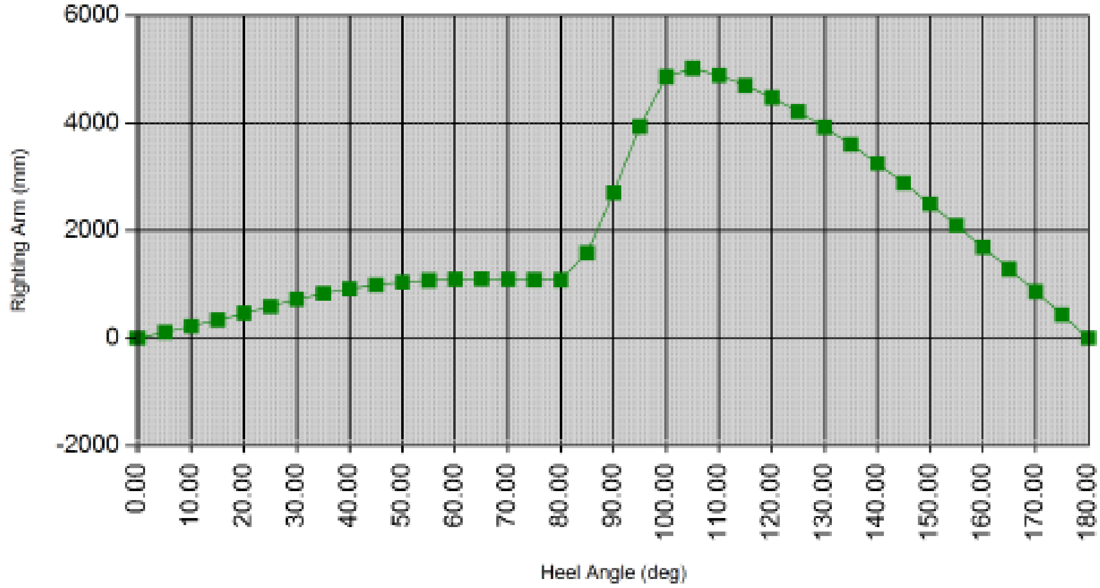
1. Locations such as the center of buoyancy and center of flotation are measured from the origin in the Rhinoceros world coordinate system.

2. The orientation of the model for an Orca3D hydrostatics solution is defined in terms of “sinkage,” “trim,” and “heel.” The sinkage value represents the depth of the body origin (i.e. the Rhino world origin) below the resultant flotation plane, and is sometimes referred to as "origin depth." Heel and trim represent angular rotations about the Rhino longitudinal and transverse axes, respectively, and are taken in that order. For a more detailed description of these terms see the Orca3D documentation.

3. Hull form coefficients are non-dimensionalized by the waterline length.

4. Calculation of Cp and Cx use Orca sections to determine Ax. If no Orca sections are defined, these values will be reported as zero.

Stability Curve



Heel(deg)	Trim(deg)	Righting Arm (mm)	Righting Moment (kgf-m)
0.000	0.000	0.000	0.0
5.000	0.000	112.199	72278.8
10.000	0.000	225.811	145467.2
15.000	0.000	342.180	220432.0
20.000	0.000	463.146	298358.2
25.000	0.000	591.309	380920.8
30.000	0.000	725.754	467530.7
35.000	0.000	835.112	537979.1
40.000	0.000	922.467	594253.0
45.000	0.000	993.853	640239.8
50.000	0.000	1044.609	672936.9
55.000	0.000	1077.676	694238.9

Innovation Centre - Orkney
Hatston Pier Road
Kirkwall
Orkney
KW15 1ZL
United Kingdom
www.orcadesmarine.co.uk

APPENDIX J – TPV CORRESPONDENCE REV 3.0

<table>
<tr><th colspan="5">TPV of “ATIR - Magallanes - Basis of Design for Mooring of a floating tidal energy converter at EMEC - Rev1”</th></tr>
<tr><th colspan="2">Comments by</th><th>Checked by</th><th>Authorized by</th><th>Date (original)</th></tr>
<tr><td colspan="2">Dynamic Systems Analysis, Bill Boggia, David Thomson</td><td>David Thomson</td><td>David Thomson</td><td>January 18th, 2018</td></tr>
<tr><th>Briefing Number</th><th>Issue Date</th><th colspan="2">Revision Details/Content</th><th>Distribution List Index Number</th></tr>
<tr><td>3.0</td><td>23.01.2018</td><td colspan="2">Mooring BOD detailed review (moorings)</td><td>1,2,3</td></tr>
<tr><th colspan="5">Distribution List Key</th></tr>
<tr><th colspan="2">Company</th><th colspan="2">Responsible Person</th><th>Distribution List Index Number</th></tr>
<tr><td colspan="2">Tadek Offshore</td><td colspan="2">Rupert Raymond</td><td>1</td></tr>
<tr><td colspan="2">Magallanes Renovables</td><td colspan="2">Pablo Mansilla</td><td>2</td></tr>
<tr><td colspan="2">Magallanes Renovables</td><td colspan="2">Marta Rivas</td><td>3</td></tr>
</table>

Introduction

This “Briefing Note” outlines a third-party verification (TPV) of the mooring analysis that will be completed by Sea Master Consulting and Engineering (SeaMaster) for the Magallanes Tidal Energy Converter. SeaMaster’s report outlining the procedure to be using to conduct a mooring analysis was reviewed and used as the basis for this verification. The report was compared with the requirements outlined in the IEC marine energy converter mooring standard.

ORCADES MARINE
Management Consultants Ltd

Innovation Centre - Orkney
Hatston Pier Road
Kirkwall
Orkney
KW15 1ZL
United Kingdom
www.orcadesmarine.co.uk

Comments	Responses (Magallanes)	Conclusion	Closed Out YES/NO
1. The document "ATIR – Magallanes – Basis of Design for Mooring of a floating tidal energy converter at EMEC – Rev1" is a description of the mooring analysis to be completed, rather than work that has been completed. The document relies mainly on "Bureau Veritas, Classification of Mooring Systems for Permanent and Mobile Offshore Units, NR 493 DT R03" and "DNV GL Offshore Standard, DNV-OS-E301, Position Mooring". DSA will rely on "IEC TS 62600-10 Assessment of mooring system for marine energy converters" (IEC standard) and "ISO 19901-7 Station keeping systems for floating offshore structures and mobile offshore units" (ISO standard) for this review.	Not Required	OK	**Yes**

ORCADES MARINE
Management Consultants Ltd

Innovation Centre - Orkney
Hatston Pier Road
Kirkwall
Orkney
KW15 1ZL
United Kingdom
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2. In section 1, a 10 yr return period is used for the analysis. The IEC standard requires a 100 yr return period for ULS and ALS. However, the ISO standard says "When the design service life of the mooring system is substantially lower than 20 years, parameters characterizing design situations with return periods shorter than 100 years may be adopted. In such cases, the return period shall be determined through a risk assessment, taking into account the possible consequences of mooring system failure." The use of a 10yr return period appears reasonable. But would need review of the risk assessment to support the case or why a 10yr return period is considered reasonable.	**The assertion of a 10-year Return period instead of 50 years is a based on the following arguments:** • **Full Class Type approval is not a requirement of this short duration prototype system.** • **The consequence of a single mooring failure is of no consequence to any other stakeholder.** • **In the single line failure case, the ALS conditions require a 1-year Return assessment and the system will be designed to survive this most onerous situation.** • **For the load cases it is assumed that the 10-year return wind speed occurs simultaneously with the 10-year Hs and that the directions are colinear. This assumption is conservative as any misalignment in the wind and wave directions will result in a reduction in the combined wind and wave load in a single direction (Refer to 7.3.5).** • **Moreover, there is likely to be some offset between extremes of winds and waves. Therefore, assuming that the 10-year return values occur colinearly is again conservative.** • **The device is a prototype and will therefore be subject to a significant monitoring regime. Monitoring of the device excursions can be carried out as well as periodic inspection using drop-down camera of the mooring anchors during routine maintenance trips to the device. This monitoring will validate the mooring design.** • **Other codes, for example API RP 2SK (Design & Analysis of Station keeping Systems for Floating Structures), propose a 5-year Return value as**		

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	acceptable for floating structures where the consequence of failure is less severe than for a FPSO full of crude oil, for example mobile offshore drilling units, and especially in cases where the unit is operating within a vicinity where there is a low potential for impact with a fixed structure. • **A risk assessment is presented in the Appendix of this report.**		

3. In section 4.1 what is meant by hydrodynamic analysis? Does it mean the Hydrostar analysis (Radiation, diffraction coefficients, etc…)? • In this list 2 items are analyses and the remainder appear to be parameters that will be obtained from the result of those analyses. • Please clarify	• Hydroydnamic analysis means the diffraction analysis. In this revision the diffraction analysis is achieved with MOSES. • Yes, it is agreed that the list is a mix of tasks and outputs and this is clarified in R02 issue		
4. A quasi-static 3hr simulation method mentioned in Section 4.1. This is only mentioned once in the document and has led to a bit of confusion as to whether or not this is a separate analysis. Please clarify	• This is an error in the text and also an inconsistency in the previous analysis approach outlined in the Basis of Design Document • The analysis work is achieved with full time domain simulations.		

5. How does Quasi-static method differ from the Quasi-dynamic method? • Please clarify			
6. Only quasi- dynamic analysis was conducted. The IEC standard requires that the final mooring installation be designed based dynamic analysis methods and corresponding safety factors are used. • The IEC standard provides slightly different safety factors for quasi-static analyses than found in the report. This may be because Quasi-static and Quasi-dynamic are two different approaches. Please clarify •	• The mooring design is not being designed to IEC. • All codes have different safety factors. • DNV-OS-E301 has been used for the sizing of all line components and links. • Gravity anchors have been sized according to engineering risk based judgements backed up by statistical and practical arguments		
7. There does not appear to be consideration of the umbilical, its impact on the system, the loads acting on the umbilical or entanglement. • The umbilical should be considered in the analyses or reasoning why not.	• The umbilical has No / Negligible influence on the mooring system and is not included in this analysis report. • Although the umbilical system is not fully designed the allowable static tension in the umbilical will be (has to be in order to be a successful design) less than a few tons. • A brief summary of the dynamic umbilical is presented in this report for information only. It is		

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	not expected that this arrangement has any influence on the approval of the station keeping ability of the mooring system proposed. • Such a small load will not influence the motion of the device or the mooring loads, other than to an unnoticeable / extremely small degree. • The umbilical system will be designed to meet the maximum excursion of the mooring system (either ULS or ALS excursion if possible) • If the maximum ULS or ALS excursion is exceeded causing the umbilical to go tight, there will be a weak link in the umbilical to ensure that it breaks and does not damage the EMEC cable.		
8. In Section 4.3, it mentions that a constant thrust load is used to model the turbine. The rotors' inertia, torque, and power take off modelling are ignored. These could produce significant loads in oscillatory flows. The inertial load can be important particularly if the rotor is pitching or yawing while operating. Please respond?	• For the purposes of a mooring design the constant thrust approach is appropriate and reasonable to avoid an extremely complex type of analysis. • This approach follows discussion with various consultants developing floating wind projects. • Although it is extremely interesting to make this assessment (using for example https://nwtc.nrel.gov/FAST) such an approach is more interesting for the local design of the blades, nacelle, turbine and control system, for system assessment and optimisation over very small time steps. • It is not necessary in this analysis and has negligible / marginal influence on mooring design.		

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	• In this application we are interested in mean loads over a few seconds in operable seastates which are pretty benign, and therefore it is appropriate and conservative to apply a constant thrust. • It is considered that the safety factors of the analysis are there to account for such simplifications in order to aim for a solutions targeted approach. • This more complex analysis will not be carried out because it is not accepted as necessary and will add significant cost to the project analysis for next to zero gain in the mooring design process.		
9. In Section 4.4, item 5 says 4 simulations will be run, then item 6 says the "maximum deterministic values from the three simulations" will be recorded. Is this a typo? 10. Please specify that these 3 or 4 simulations are different sea state realisations and why 3 or 4 simulations are enough to ensure consistent statistics of extreme peak responses. (See IEC standard section 9.5.3)	• Yes, this does seem to be a typo and will, be clarified. • The results present the maximum results from the three-hour simulations to show that the selection of 4 time histories creates a sufficient sample of maxima. • Such an approach is recommended in DNV-OS-301 also. • We are not familiar with the IEC standard or all codes but we understand that most follow a similar approach on this matter.		
11. In Section 4.4, can you clarify that item 7 is referring to both ULS and ALS load cases?	• The loads from the analysis are factored (by different factors) as required for the ULS or ALS conditions. • All factored loads must be below the component MBL		

12. It's a fair assumption, by reading the document, that ULS and ALS cases will be conducted. Please clarify 13. Section 4.5 describes what ULS and ALS cases are rather than state clearly that ULS and ALS checks will be conducted. The report should make clear that all load cases in Section 10 are ULS checks, and that ALS checks will be conducted as described in 4.5.2. Please clarify	• Yes this is correct. ULS and ALS cases are conducted. • Understood. ALS cases will be performed as clarified in the Load Case matrix of R02		
14. The IEC standard requires consideration of Serviceability Limit State (SLS) and Fatigue Limit State (FLS). Some text stating that these have been considered and why load cases don't need to be generated for them should be provided. (The reasoning could be due to the short-term deployment and a low associated risk of failure).	• Some text is added here on the consideration of these states		
15. In Section 5.2.3 have yaw moments caused by wind loading been considered?	• Yes.		

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16. In Section 5.2.5, it's not clear how the yaw moments from currents are determined. It appears that a yaw rate is 0 would result in a zero-yaw moment. Yaw moments that are proportional to yaw angle are expected. Please clarify • The yaw moments are important as they could lead to yaw oscillations due interaction between the hydrodynamic yaw loads and the mooring restoring loads. Particularly since the device lacks yaw stabilisers. Such yaw oscillations could lead to extra dynamic mooring loads. It's important that these hydrodynamic yaw loads and their interactions with the moorings are reasonably modelled. 17. Has the possibility of yaw oscillations building up, even under steady loading, been considered? •	• The yaw coefficients as a function of angle are presented in Section 7 • Yaw assessment is implicit within the analysis via: o A first order frequency dependent yaw moment o Mean drift yaw moment o Current yaw moment o Wind yaw moment A yaw moment is applied as a function of the excitation force and the incident angle at each time step. The yaw moment is restrained by the mooring system. Yaw oscillations have been seen in some simulations and the prevention of these is one other reason for the four legs with the two legs split at 45 degrees.		
18. Has added mass related destabilising moments such as the Munk moment been considered? •	No the Munk moment has not been added as an additional coefficient because it is considered to be normally more significant and relevant to bodies without yaw restraint. Our system has some yaw restraint from the spread four legged mooring system.		

	Irrespective of this, yaw caused by eccentric current and wave directions is a cause of higher loads and any destabilising moments from Munk moments are likely to be small compared to these combined potential and viscous yaw moments.		
19. Section 5.5/Table 5.5 shows the drag loads for a combination of the upper and vertical blocks. How it applies to the hydrodynamics model used in the mooring analysis is not clear. • Some clarification of how the drag loads are modelled should be included. For example, where are these drag loads applied? At the CG? Surface integral? 20. There is no mention of the centers of pressure caused by the drag loads on the upper, vertical or lower blocks or how they create roll and pitch moments. The roll moments and motions if significant enough will have an influence on the dynamics of the mooring system. Roll moments will arise since the platform will experience some relative yaw displacements.	• A schematic has been added to clarify how these coefficients are applied • The centres of pressure for the combined drag coefficients have been derived via the initial development of drag coefficients using CFD, OCIMF and DNV-RP-C205. • Sway drag loading on the lower block is not ignored. • Roll moments are not ignored due to the centres of drag calculated		

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• Sway drag loading on the lower block is ignored but could lead to significant roll moments. If roll moments are to be ignored, some justification required.			
21. Section 7, have load cases where the brake failed or the hydraulic accumulator failed leaving the blades in an operating pitch state or freewheeling been considered? Please clarify	It is not possible for the blades to operate in a free wheeled pitch state.		
22. Section 7 - There is a mismatch of current velocity for Condition 2: 3.6m/s and 3.5m/s (Table 7-2) Please clarify	• Yes – this is a typo and should say 3.5m/s in the bullet. This achieves the coefficient of 0.16. To maintain a conservative analysis this value is used in the current cases where there is a3.6m/s current. • For the EBB condition with a maximum flow of 3.6m/s this is marginally conservative		
23. Table 7-2 caption says it includes AM coefficients, but it appears that it does not. Please clarify	• Thanks, this is corrected.		

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24. Are the drag coefficients and loads discussed in Section 7 for a single rotor only or both combined? 25. Has flow shadowing been considered?	• For a single rotor • No. For the sake of developing maximum mooring design loads, it is conservatively assumed there is no shadowing and that both blades will produce maximum thrust. • In reality there will be some testing performed during the initial operation to: optimise overall power output by modifying blade pitch, also to assess if there is any directional stability improvement by reducing the thrust of the upstream turbine		
26. Section 7.1.2 mentions a thrust load of 645kN @ 2.5m/s. Later when determining the reduced drag coefficient at 3.5m/s, a value of 680kN is used. Please clarify	• Thanks, yes this seems to be an error and is corrected		

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27. Section 7.1.3 mentions the inertia coefficient (Cm) and its relationship to the added mass coefficient (Ca) • The added mass coefficient Ca helps define the added mass load caused by the relative fluid acceleration. • The Froude-Krylov load, a wave excitation load, accounts for the +1 component of Cm, but is not part of the added mass force. For example, the Froude-Krylov load is accounted for in the wave excitation loads from BEM solvers (Hydrostar). The wave excitation load includes the Froude-Krylov load as well as the Diffraction load. Special care should be taken here to not accidently overestimate the added mass load by confusing Cm with Ca. The added mass coefficient (Ca) used should be reported. Please confirm •	• What is the Ca value used ? • A value of 1 is used for a blade with a constant cross section of 1.0 x 0.3m • The added mass is not over estimated because the MOSES hydrodynamic modelling does not include the blades.		
28. Section 9.2, the report should cite the source for the marine growth thickness values used. Please clarify	• DNV-OS-E301		
29. Section 10, it is expected the worst case loading conditions for the mooring are during the 10yr flood/ebb flows while the turbine is operational. Why are the wave and wind	• The device will not be operated in 1yr or 10yr environmental conditions but braked.		

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conditions chosen for these operational cases not the 10yr return period wave/wind that corresponds to those current speed and wave direction bins? • Both the 1 yr and 10 yr return period Hs for these current speeds and wave directions are greater than the 1.8m Hs chosen for these operational cases.			
30. What environmental conditions would trigger the system to go into survival mode. Is Hs = 1.8m a limitation to the operational state?	• Yes. Hs 1.8m is an initial environmental limit until tests prove otherwise. • Greater clarity on the operational philosophy is presented in this revision		
31. Operational loading on the turbine required. Turbine tip speed ratio's in different cases (with thrust and torque applied) • 32. Summary of operational mooring loads required for fatigue and structural design checks?	• This is outside the scope of the mooring design report which is interested in the maximum thrust loads only which exert forces on the mooring lines. • The loads are reported in this revision		

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APPENDIX K – TPV CORRESPONDENCE REV 4.0

TPV of “ATIR - Magallanes - Basis of Design for Mooring of a floating tidal energy converter at EMEC - Rev1”			
Comments by	**Checked by**	**Authorized by**	**Date (original)**
David Thomson	David Thomson	David Thomson	03.03.2018
Briefing Number	**Issue Date**	**Revision Details/Content**	**Distribution List Index Number**
4.0	03.03.2018	*TDK-MAG-MOOR-TR-001-R01*	1,2,3

Distribution List Key		
Company	**Responsible Person**	**Distribution List Index Number**
Tadek Offshore	Rupert Raymond	1
Magallanes Renovables	Pablo Mansilla	2
Magallanes Renovables	Marta Rivas	3

Introduction

Extract from report to which this briefing note refers:

“This report was originally issued in R01 as a Seamaster document, written principally by Tadek. This revision follows from this R01.However, the document is now issued as a Tadek document and therefore is issued as TDK-MAG-MOOR-TR-001-R01. The modelling approach and development of coefficients remains largely unchanged except to reflect some comments issued by the TPV to R01. The principal change is that the mooring design loads are now derived differently from that described in the basis of design document. Instead of using Hydrostar and Ariane to define the loads, MOSES and Orcaflex are used.”

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Comments	Responses (Magallanes)	Conclusion	Closed Out YES/NO
1. Section 1.1 P9 include mention of structural attachments in the TPV "the work that is required to satisfy a TPV that: • Mooring components and structural attachments…..	**Section 1.1 is updated with this addition**		
2. Section 2.2 re-confirm size of clump weights NW,NE,SE,SW	**Section 2.2 is now updated**		
3. Tables 2.2 and 2.3 please clarify derivation of content	**Paragraph added to section 2.5**		
4. Section 3 a) 16. Please provide actual source (from EMEC) of metocean data that has been used in this analysis or direct us to the link b) Would be useful to have a summary table of extremes Wind/Hs/current used	**Supplied**		

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	Please refer to Section 10 and the Load case tables in Section 11		

5. Table 2.1 confirm excursion distance is in metres	**The excursion is reported in all results tables**		

6. Section 2.5 (and 6.5.2 and 11.2) a) Monitoring - Explain in detail how the device will be monitored - by whom and how are alerts received. List the elements (GPS, number and location of load cells, other instrumentation, motion?) that are to be monitored. b) Modify – Outline methodology for practical modification of the system when on station c) Coeff of friction – Please provide drag trial documentation Section 9.6.6 (AHH Operations FoW 2012?) d) Can you provide a verifiable estimate of the distance that a clump weight would shift during the peak	**Answered in Section 2, 3 and 4 below.** **A sentence is added clarifying this** **This memo is now included in Appendix I.**		

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loading strikes? And therefore, provide an estimate of the cumulative effect over the 3-hour period?			
7. Section 7.5 – The bottom block does not appear to be included to determine the current coefficients (Table 7-5)	**Some clarification of how the nacelle drag coefficients are calculated within an analytical method is included. However, Table 7-5 is no longer interesting for the TPV because the drag coefficients used in the analysis are those derived from the upper bound value from the drag trials and CFD.**		

8. Section 7.6 - Please include statement of condition of lower blades (on or off/ fixed) during tow trials.	**There were no blades fitted**		
9. Section 8.1.3 is the generator required to kick in to bring blades back to failsafe	No, there is a specific oil pump that moves the pitch system. This pump is isolated from the generating system.		

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10. Section 9.6.2 Please provide the structural calculations for the single attachment point	These have been supplied in PD.REP.0020 ATIR Platform mooring point analysis.rev0 and further details supplied by Seamaster. This report, in 14 presents a further assessment of loads during the moori		
11. Section 9.6.6 – please clarify sentence "With the above in mind….0.6 may be forced"	Added "may be forced because it is the most conservative value and therefore the easiest to force without question or challenge using engineering or operational experiences."		

12. Section 10.1 tidal range – source data. Nearest secondary port at Rapness has range of 4.2 metres	**OK**		
13. Section 10.5 Current Rose – (see also request 4 above) is this from ADCP data and what was its location relative to ATIR site	**Location has been clarified in Figure 10-1. This is not ADCP data but modelled data. Experiences with the modelled data from EMEC has been**		

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	found in the past to be reasonable but in this example the actual data		

14. Section 11.1, 11.2 Ballasting a) Can you provide more information on the normal and backup power/system any redundancy in components for the ballasting system (how is failure mitigated against) b) If the ballasting system fails, with the upstream tank full, what would be the effect on trim at maximum operating current c) Have any FME calculations been carried out for this case?	**a) Three water pumps will move the water between tanks depending on the requirements of each situation. Generally only one or two of these pumps will work but in an emergency situation all pumps can work at the same time.** **b) Firstly we can stop the platform in case a big fail occurs. But it is quite improbable that all the ballast system fails, may fall a pump or two or some valves, but the system will continue working.** **c) No. A number of pumps have been specified to deal with a failure.**		

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15. Section 11.2. a) Will need to define "motion" parameters	**During the initial testing the performance of the turbine as a function of pitch and roll will be assessed and the influence on loads. These motion parameters will therefore be defined within the initial ramp of up the testing period.**		
16. Figure 11.4 a) Confirm load cells at each end? b) Are the Crosby load cells the primary shackle, not Green Pin as per Figure 9-12 c) An inspection procedure should be defined for the O&M phase	**a) There will be a load cells (Crosby load cell) at each end of the mooring line, as specified in Figure 11-4.** **b) The primary shackle should be a Green Pin because the pin diameter fits better. After this shackle a Crosby load shackle is proposed assessing load in one leg.**		

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	c) Yes, there will be extensive monitoring of the platform during operation		
17. Table 12.1 and 12.2 – Please clarify significance of colour shading in wave height	Red is big, Green is small, Orange/Yellow is medium		

18. Appendix F – Risk Assessment, parameters to be inserted and completed	This will be done in due course but is not deemed critical to this TPV of design		
19. General – Has there been a check on the stability – trim and freeboard on the device with the loading of moorings cable etc?	The device is extremely stable as per Appendix APPENDIX J – STABILITY ASSESSMENT showing a GMT of 1.3 and a range of stability of 180 degrees. In no simulations is there any indication of loss of stability.		

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APPENDIX L – TPV CORRESPONDENCE REV 5.0

<table>
<tr><th colspan="5">TPV of “ATIR - Magallanes - Basis of Design for Mooring of a floating tidal energy converter at EMEC - Rev1”</th></tr>
<tr><td colspan="2">Comments by</td><td>Checked by</td><td>Authorized by</td><td>Date (original)</td></tr>
<tr><td colspan="2">Dynamic Systems Analysis Ltd.</td><td>David Thomson</td><td>David Thomson</td><td>March 9th, 2018</td></tr>
<tr><td>Briefing Number</td><td>Issue Date</td><td colspan="2">Revision Details/Content</td><td>Distribution List Index Number</td></tr>
<tr><td>Rev 5.0</td><td>12.03.2018</td><td colspan="2">TDK-MAG-MOOR-TR-001-R01</td><td>1,2,3</td></tr>
<tr><td colspan="5">Distribution List Key</td></tr>
<tr><td colspan="2">Company</td><td colspan="2">Responsible Person</td><td>Distribution List Index Number</td></tr>
<tr><td colspan="2">Tadek Offshore</td><td colspan="2">Rupert Raymond</td><td>1</td></tr>
<tr><td colspan="2">Magallanes Renovables</td><td colspan="2">Pablo Mansilla</td><td>2</td></tr>
<tr><td colspan="2">Magallanes Renovables</td><td colspan="2">Marta Rivas</td><td>3</td></tr>
</table>

Introduction

Section 1 of this “Briefing Note” Rev 5.0 provides comments specifically on the mooring analysis as described in *TDK-MAG-MOOR-TR-001-R01.*

The previous Brief Note No 3, provided comments to Seamaster Document Rev 1. The responses to Briefing Note 3 from Magallanes were included in the revised document *TDK-MAG-MOOR-TR-001-R01* (Appendix B). Close out on these comments and outstanding items are also included in this Briefing Note, in Section 2.

Section 1

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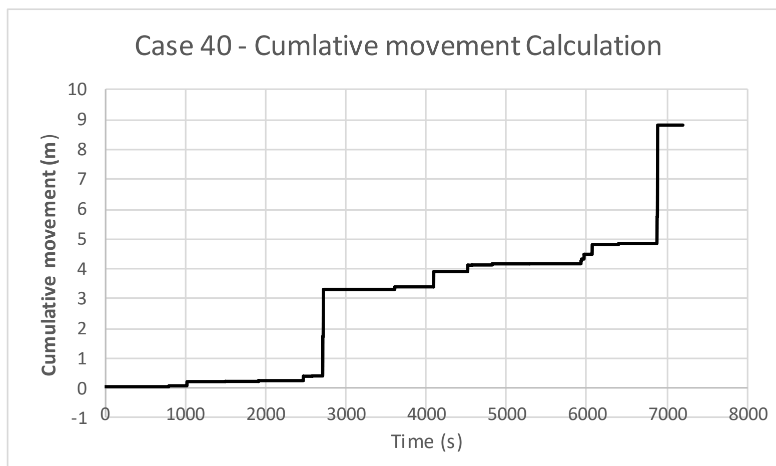
Comments	Responses (Magallanes)	Closed Out YES/NO
1. The thrust loads on the turbine are a significant source of loading on the mooring. Accurately capturing the thrust loads is critical. An assumption or approximation is made about the turbine's thrust loads around the blade pitch moment. This is fine, if no other information is available about the turbine's performance. Nevertheless, it adds some degree of uncertainty about the accuracy of the modelled loads in the high current regimes because the load distribution on the blades is unknown.	**Yes, this is true. However, the governing cases are not when the turbines are operating.** **Although there is uncertainty, even if they were as much as 10% inaccurate the mooring design, they do not influence the component sizes.** **During the initial testing process the actual forces will be measured, and in the unlikely event of the thrust loads from the turbine now driving mooring component sizes, the mooring clumps will be adjusted as described briefly in Section 2.5.**	

2. In Section 13.2, some justification should be provided for why this analysis does not need to be reproduced for the final mooring design. 3. Which system revision is being discussed in Section 13.2?	**Because there are enough examples assessed to provide the point that that peak loads are of short duration and further engineering hours proving this point to more minute detail is not deemed sufficiently productive for this project especially considering the significant monitoring the device will experience.**	
4. Section 13.3.4 Class 2 is a copy-paste from Failure Level 1.	**Section 13.3.4 has been re-written**	

<table>
<tr>
<td>5. The method used for determining anchor displacements of 1-2m is unclear. Section 6.1 claims that anchor horizontal and vertical loads are reported but only anchor tensions are. Do the vertical loads at the anchors factor into the maximum required anchor holdage or anchor motions?</td>
<td>The 1-2m was an intuitive estimate without any engineering basis. Some calculations have now been done by taking the duration of the over-utilisation force (accounting for any vertical component of force degrading the anchor capacity), transferring it into an acceleration, and a resulting velocity and displacement over the duration of the over-utilisation. Total movement considering an impossible constant current velocity over three hours were found to be around 10m with a maximum single event of just over 2m. A constant three-hour duration of force is not feasible. Therefore the total movement remains close to the intuitive estimate without engineering basis.



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6. Section 13 does not present the factored loads in the moorings for the ALS cases. Results aren't presented like they were for the ULS cases.	**This is now updated to present loads in the same way**	
7. In Section 13, it is unclear what the MBL is for the moorings? It appears to be ~250te. What value corresponds to a red cell?	**There is not an MBL for the mooring system. All component MBLs are sized according to Section 6.5.** **This is merely excel conditional formatting. A red cell is a large value, an orange / yellow is more moderate and green are the lower values.**	

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8. General Observation on presentation and format • On pg 21 6. Determine, using appropriate factors (as described in Section 0) the design load. (there is no section 0) • In Section 7.2.3 A should be alpha - correct? • In Section 7.2.5 What's the difference between Cy, Cyaw, and Cmz? • On pg 45 in figure for Design Evolution R02, are the moorings mislabelled? • In Figure 13-1 and forward. These are tables rather than figures. • All weather directions in the report use "heading towards" convention in section 10. But section 12 says it uses "direction from" convention. This is leading to some confusion about the load cases. • Table 13-1 to 13-4 would be helpful to add column with case #s	• **Corrected** • **Corrected** • **Corrected** • **Corrected** • **Corrected** • **Corrected** • **Agreed. This has been extremely confusing following a poor decision early on to define within the environmental modelling section a heading convention TO which went against intuition and normal convention. Section 12 changes to Heading FROM because this makes more sense to understand. It is not possible without significant work to change the convention in earlier sections and therefore this point is asserted as an inconvenience as opposed to an error and will not be changed.** • **Added**	**Advisory only**

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Section 2

Further comments to Magallanes Response to Briefing Note 3 included as Annex B in document TDK-MAG-MOOR-TR-001.			
Reference Number from Briefing Note 3	**Outstanding Comments**	**Response**	**Closed out?**
1 to 9, 11 to 15, 17, 28-32.	OK		Yes

10.	Can you elaborate on the three simulations completed? Specifically, can they comment on whether or not they represent three different sea state realisations?	**Yes, they are three different random wave seeds**	
16.	It is still not clear based on Section 7 how the yaw moment based on angle of incidence is modelled or if this is based on an accepted practice cited in a reference or standard or validated in some way.	**The section has been updated because the trend of the yaw coefficients (with a maxima at 90 degrees) had been changed in error based on**	

	For a symmetric body, a zero yaw moment would be expected under pure beam loading. Nevertheless, this approach is producing destabilising moments that is therefore incorporated in the mooring analysis. The report could be clarified by describing the relationship between Cy, Cyaw and Cmz. Section 7.2.5 mentions a Cmz of 1.7 in beam loading which doesn't appear in Table 7-5.	**some Cmz results derived in MOSES which were not correct.** **This report now reverts to the original description of the derivation.** **There is some further clarification on the derivation of the method in APPENDIX H – EQUIVALENT YAW CALCULATION OF RECTANGULAR BOX**	

19-20.	The report does not describe how the sway drag loading on the lower block is modelled. A description similar to vertical block would help clarify this. DSA accepts the statement that roll moments caused by sway drag load centers of pressure are being modelled.	**This is now presented, albeit it is only useful for the modelling of the centre of drag as opposed to the overall drag coefficient because the overall drag coefficient is derived from the drag trials.**	

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Hatston Pier Road
Kirkwall
Orkney
KW15 1ZL
United Kingdom
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	The report does not describe how the sway drag loading on the lower block is modelled. A description similar to vertical block would help clarify this. DSA accepts the statement that roll moments caused by sway drag load centers of pressure are being modelled.		
27.	This response is fine. Equation on page 43 shows Cm, which is the inertia coefficient. Ca, the added mass coefficient, is given by Ref[6, Appendix d], not Cm. Ca = 1 is appropriate.		Yes

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Hatston Pier Road
Kirkwall
Orkney
KW15 1ZL
United Kingdom
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APPENDIX M – TPV CORRESPONDENCE REV 2.0

TPV of "ATIR - Magallanes - Basis of Design for Mooring of a floating tidal energy converter at EMEC - Rev1"				
Comments by		**Checked by**	**Authorized by**	**Date (original)**
Dynamic Systems Analysis Ltd.		David Thomson	David Thomson	March 29th, 2018
Briefing Number	**Issue Date**	**Revision Details/Content**		**Distribution List Index Number**
Rev 6.0	29.03.2018	*TDK-MAG-MOOR-TR-001-R02*		1,2,3
Distribution List Key				
Company		**Responsible Person**		**Distribution List Index Number**
Tadek Offshore		Rupert Raymond		1
Magallanes Renovables		Pablo Mansilla		2
Magallanes Renovables		Marta Rivas		3

Content

Innovation Centre - Orkney
Hatston Pier Road
Kirkwall
Orkney
KW15 1ZL
United Kingdom
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Part 1

Is the response to the submission of the second revision Tadek document *TDK-MAG-MOOR-TR-001-R02. TDK-MAG-MOOR-TR-001-R02* and the new information contained within

Part 2

The *Appendix J of TDK-MAG-MOOR-TR-001-R02* compiles responses to Briefing Notes 3, 4 and 5 previously issued by the TPV Provider, this Section 2 completes the "close out" with comments where appropriate.

PART 1

Section 1

Comments	Responses (Magallanes)	Closed Out YES/NO
1. 1.3.1 the approximated fatigue calculations we have used are indicative of significant potential for early fatigue failure on the main shackle. This concern has not been specifically addressed. An intensive inspection regime in the early days of deployment may be accepted but we would like clarification on your approach to this.	**The fatigue calculations in the Orcades Marine report 'Magallanes TPV – Structural – Rev 3' are based on the very high contact stresses that are found in Orcades Marine's FE calculations.** **The oblique mooring loads are lower than those assessed in the Orcades report which were derived not using input from the simulations but via an incorrect back calculating method which applied a simplistic assumption of loads relative to the static position. This was combined with a maths error resulting in an oblique assessment of a 246Te load at 50 degrees instead of 32 degrees.**	

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Hatston Pier Road
Kirkwall
Orkney
KW15 1ZL
United Kingdom
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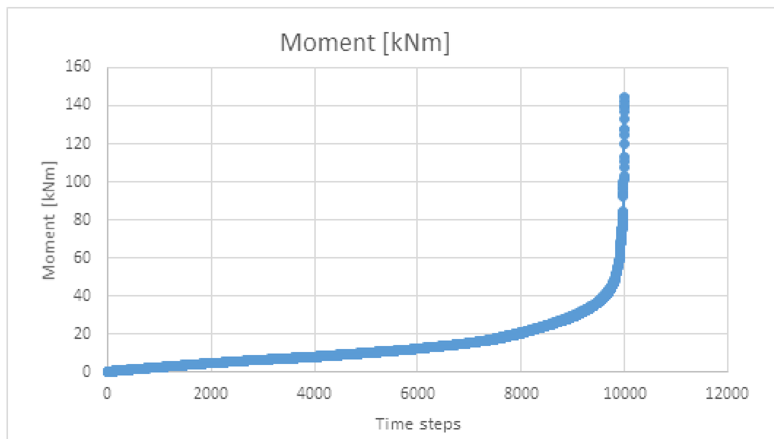
	Furthermore, in the Orcades Marine report a linear distribution of the waves is assumed between 0 and the maximum occurring forces. When we look at the bending moment on the mooring eye analysis of our data shows that out of 10000 time steps 9500 show a more or less linear distribution between 0 and 25% of the maximum force. The remaining 500 time steps show a more or less linear distribution between 25% and 75% of the maximum force. Therefore, taking a linear distribution across the full range is considered far too conservative. Additionally these statistics show that the maximum loads are very rare events within these 10-year return conditions. 	

	However, on the basis that there remains is some significant bending in the padeye, it is proposed to replace the shackle with a more a compact structure as presented in Figure 14-15 that further reduces the bending moments. One governing load case assessed resulted in a bending moment on the padeye with the shackle arrangement of 382 kNm and a bending moment with this new configuration is reduced to 145 kNm. The (preliminary design) of this structure has been checked for 20000 time steps of different load cases and it showed that the pin is no longer jammed in the hole and is therefore not bearing on the edge of the hole. **It is felt that the highly onerous fatigue conclusion by Orcades report 'Magallanes TPV – Structural – Rev 3' is mitigated, in part due to the highly conservative nature of the Orcades analysis, in part due to errors in that analysis and in part due to the far lower stresses experienced by the simple padeye and internal hull structure due to the revised padeye connection.** **Furthermore, the device will be subject to an extensive inspection regime. This can be achieved internally via inspection inside the ballast tank and externally via assessment of the padeye. This latter inspection can be achieved by ballasting the device to gain access to the padeye above water.**	

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Hatston Pier Road
Kirkwall
Orkney
KW15 1ZL
United Kingdom
www.orcadesmarine.co.uk

ORCADES MARINE	Calculation Sheet	
	By: WJB	17th March 18
	Checked By: WJB	17th March 18

The output catenary angles to the horizontal for the Survival Case 40 mooring lines are shown below.

$\theta nw\_40 := 21.37\ deg$ $\qquad \theta sw\_40 := 39.07\ deg$

$\theta ne\_40 := 52.4\ deg$ $\qquad \theta se\_40 := 44.69\ deg$

The horizontal and Vertical Moorin Line Forces for each line are as follows:

NW horizontal $\quad Fh\_nw\_40 := Fnw\_40 \cdot \cos(\theta nw\_40) = 200.218\ tonne$

NW vertical $\quad Fv\_nw\_40 := Fnw\_40 \cdot \sin(\theta nw\_40) = 78.344\ tonne$

NE horizontal $\quad Fh\_ne\_40 := Fne\_40 \cdot \cos(\theta ne\_40) = 29.287\ tonne$

NE vertical $\quad Fv\_ne\_40 := Fne\_40 \cdot \sin(\theta ne\_40) = 38.03\ tonne$

SW horizontal $\quad Fh\_sw\_40 := Fsw\_40 \cdot \cos(\theta sw\_40) = 65.216\ tonne$

SW vertical $\quad Fv\_sw\_40 := Fsw\_40 \cdot \sin(\theta sw\_40) = 52.943\ tonne$

SE horizontal $\quad Fh\_se\_40 := Fse\_40 \cdot \cos(\theta se\_40) = 48.343\ tonne$

SE vertical $\quad Fv\_se\_40 := Fse\_40 \cdot \sin(\theta se\_40) = 47.822\ tonne$

The horizontal load components at the vessel mooring points - in relation to the vessel axis are as follows:

$Fxn\_40 := Fh\_nw\_40 \cdot \cos(\theta nw\_v) + Fh\_ne\_40 \cdot \cos(\theta ne\_v) = \cancel{142.361}\ tonne$ 183,12

$Fzn\_40 := Fh\_nw\_40 \cdot \sin(\theta nw\_v) + Fh\_ne\_40 \cdot \sin(\theta ne\_v) = \cancel{174.026}\ tonne$ 115,98

$Fyn\_40 := Fv\_nw\_40 + Fv\_ne\_40 = 116.374\ tonne$

$Fxs\_40 := Fh\_sw\_40 \cdot \cos(\theta sw\_v) + Fh\_se\_40 \cdot \cos(\theta se\_v) = 94.781\ tonne$

$Fzs\_40 := Fh\_sw\_40 \cdot \sin(\theta sw\_v) - Fh\_se\_40 \cdot \sin(\theta se\_v) = 23.81\ tonne$

$Fys\_40 := Fv\_sw\_40 + Fv\_se\_40 = 100.765\ tonne$

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ORCADES MARINE	Calculation Sheet	
	By: WJB	17th March 18
	Checked By: WJB	17th March 18

North Attachment Resultant Load

$Natt\_40 := (Fxn\_40^2 + Fyn\_40^2 + Fzn\_40^2)^{0.5} = \cancel{253.169}\ tonne$ 246

Tadek Values

$Natt\_40\_t := 246\ tonne$

South Attachment Resultant Load

$Satt\_40 := (Fxs\_40^2 + Fys\_40^2 + Fzs\_40^2)^{0.5} = 140.371\ tonne$ $\qquad Satt\_40\_t := 111\ tonne$

The component mooring point forces are factored so that their resultant magnitude is in keeping with the TADEK values as follows:

$Natt\_factor := \frac{Natt\_40\_t}{Natt\_40} = 0.972$ $\qquad Satt\_factor := \frac{Satt\_40\_t}{Satt\_40} = 0.791$

$Fxn\_40 := Fxn\_40 \cdot Natt\_factor = 138.33\ tonne$

$Fzn\_40 := Fzn\_40 \cdot Natt\_factor = 169.098\ tonne$

$Fyn\_40 := Fyn\_40 \cdot Natt\_factor = 113.078\ tonne$

$Natt\_40 := (Fxn\_40^2 + Fyn\_40^2 + Fzn\_40^2)^{0.5} = 246\ tonne$ **Check - OK**

$Fxs\_40 := Fxs\_40 \cdot Satt\_factor = 74.949\ tonne$

$Fzs\_40 := Fzs\_40 \cdot Satt\_factor = 18.828\ tonne$

$Fys\_40 := Fys\_40 \cdot Satt\_factor = 79.681\ tonne$

$Satt\_40 := (Fxs\_40^2 + Fys\_40^2 + Fzs\_40^2)^{0.5} = 111\ tonne$ **Check - OK**

Transverse Mooring Load Angle - North

$\beta n\_40 := \mathrm{atan}\left(\frac{Fzn\_40}{Fxn\_40}\right) = \cancel{50.715}\ deg$ 32,35

Resultant Shackle Angle to Horizontal

$\alpha n\_40 := \mathrm{atan}\left(\frac{Fyn\_40}{Fxn\_40}\right) = \cancel{39.264}\ deg$ 44,903

Transverse Mooring Load Angle - South

$\beta s\_40 := \mathrm{atan}\left(\frac{Fzs\_40}{Fxs\_40}\right) = 14.102\ deg$

Resultant Shackle Angle to Horizontal

$\alpha s\_40 := \mathrm{atan}\left(\frac{Fys\_40}{Fxs\_40}\right) = 46.753\ deg$

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Kirkwall
Orkney
KW15 1ZL
United Kingdom
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ORCADES MARINE	Calculation Sheet	
	By: WJB	17th March 18
	Checked By: WJB	17th March 18

The output catenary angles to the horizontal for the Survival Case 2 mooring lines are shown below.

$\theta nw\_2 := 21.37\ deg$ $\qquad \theta sw\_2 := 39.07\ deg$

$\theta ne\_2 := 52.4\ deg$ $\qquad \theta se\_2 := 44.69\ deg$

The horizontal and Vertical Moorin Line Forces for each line are as follows:

NW horizontal	$Fh\_nw\_2 := Fnw\_2 \cdot \cos(\theta nw\_2) = 16.762\ tonne$
NW vertical	$Fv\_nw\_2 := Fnw\_2 \cdot \sin(\theta nw\_2) = 6.559\ tonne$
NE horizontal	$Fh\_ne\_2 := Fne\_2 \cdot \cos(\theta ne\_2) = 6.712\ tonne$
NE vertical	$Fv\_ne\_2 := Fne\_2 \cdot \sin(\theta ne\_2) = 8.715\ tonne$
SW horizontal	$Fh\_sw\_2 := Fsw\_2 \cdot \cos(\theta sw\_2) = 57.452\ tonne$
SW vertical	$Fv\_sw\_2 := Fsw\_2 \cdot \sin(\theta sw\_2) = 46.64\ tonne$
SE horizontal	$Fh\_se\_2 := Fse\_2 \cdot \cos(\theta se\_2) = 83.889\ tonne$
SE vertical	$Fv\_se\_2 := Fse\_2 \cdot \sin(\theta se\_2) = 82.986\ tonne$

The horizontal load components at the vessel mooring points - in relation to the vessel axis are as follows:

$Fxn\_2 := Fh\_nw\_2 \cdot \cos(\theta nw\_v) + Fh\_ne\_2 \cdot \cos(\theta ne\_v) = 19.334\ tonne$

$Fzn\_2 := Fh\_nw\_2 \cdot \sin(\theta nw\_v) + Fh\_ne\_2 \cdot \sin(\theta ne\_v) = 12.844\ tonne$

$Fyn\_2 := Fv\_nw\_2 + Fv\_ne\_2 = 15.274\ tonne$

$Fxs\_2 := Fh\_sw\_2 \cdot \cos(\theta sw\_v) + Fh\_se\_2 \cdot \cos(\theta se\_a) = 119.409\ tonne$

$Fzs\_2 := Fh\_sw\_2 \cdot \sin(\theta sw\_v) - Fh\_se\_2 \cdot \sin(\theta se\_a) = 0.155\ tonne$

$Fys\_2 := Fv\_sw\_2 + Fv\_se\_2 = 129.626\ tonne$

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ORCADES MARINE	Calculation Sheet	
	By: WJB	17th March 18
	Checked By: WJB	17th March 18

The output catenary angles to the horizontal for the Operational Case 105 mooring lines are shown below.

$\theta nw\_105 := 75.77\ deg$ $\qquad \theta sw\_105 := 46.35\ deg$

$\theta ne\_105 := 81.29\ deg$ $\qquad \theta se\_105 := 30.3\ deg$

The horizontal and Vertical Moorin Line Forces for each line are as follows:

NW horizontal	$Fh\_nw\_105 := Fnw\_105 \cdot \cos(\theta nw\_105) = 3.196\ tonne$
NW vertical	$Fv\_nw\_105 := Fnw\_105 \cdot \sin(\theta nw\_105) = 12.601\ tonne$
NE horizontal	$Fh\_ne\_105 := Fne\_105 \cdot \cos(\theta ne\_105) = 1.514\ tonne$
NE vertical	$Fv\_ne\_105 := Fne\_105 \cdot \sin(\theta ne\_105) = 9.885\ tonne$
SW horizontal	$Fh\_sw\_105 := Fsw\_105 \cdot \cos(\theta sw\_105) = 44.176\ tonne$
SW vertical	$Fv\_sw\_105 := Fsw\_105 \cdot \sin(\theta sw\_105) = 46.308\ tonne$
SE horizontal	$Fh\_se\_105 := Fse\_105 \cdot \cos(\theta se\_105) = 107.061\ tonne$
SE vertical	$Fv\_se\_105 := Fse\_105 \cdot \sin(\theta se\_105) = 62.561\ tonne$

The horizontal load components at the vessel mooring points - in relation to the vessel axis are as follows:

$Fxn\_105 := Fh\_nw\_105 \cdot \cos(\theta nw\_v) + Fh\_ne\_105 \cdot \cos(\theta ne\_v) = 3.906\ tonne$

$Fzn\_105 := Fh\_nw\_105 \cdot \sin(\theta nw\_v) + Fh\_ne\_105 \cdot \sin(\theta ne\_v) = 2.529\ tonne$

$Fyn\_105 := Fv\_nw\_105 + Fv\_ne\_105 = 22.486\ tonne$

$Fxs\_105 := Fh\_sw\_105 \cdot \cos(\theta sw\_v) + Fh\_se\_105 \cdot \cos(\theta se\_v) = 130.067\ tonne$

$Fzs\_105 := Fh\_se\_105 \cdot \sin(\theta se\_v) - Fh\_sw\_105 \cdot \sin(\theta sw\_v) = 18.537\ tonne$

$Fys\_105 := Fv\_sw\_105 + Fv\_se\_105 = 108.87\ tonne$

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Hatston Pier Road
Kirkwall
Orkney
KW15 1ZL
United Kingdom
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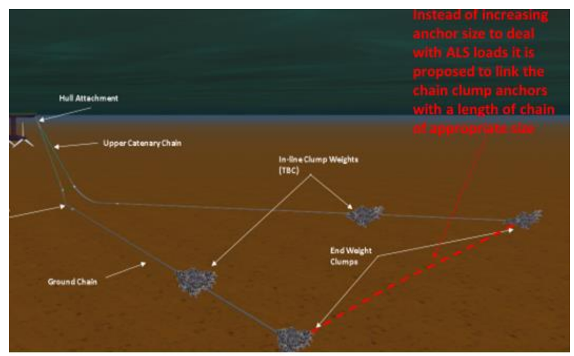
1. 1.3.2 Do the modifications to the mooring affect the geometry in any conditions and can you please confirm that the optimised mooring system has been re-modelled in Orcaflex, and the results from there, are that shown in Rev 2 (incl ALS 13.3) 2. 1.4 change from chain to solid steel will change for coefficient of friction. Please confirm this will be taken into account in the optimisation	**Perhaps this question is not understood so please accept our apologies. Modifications to the mooring are themselves a slight modification of the geometry so the question is not quite understood. The revised system has been fully modelled in Orcaflex and the system has been fully modelled in Orcaflex. All results reflect this modified model.** **Absolutely. The procurement process will govern. But the technical solution accounting for gravity block friction coefficient must categorically be taken into account. It is premature to do this now. Once the least cost procurement strategy is achieved to enable this research and development project, any variation in friction coefficient will be reported.**	

Section 2

3. 2.1 Fig 2.1 and Fig 9.1 do these still represent the plan view of the geometry with the mooring modifications?	**Actually this figure had not been updated and is now in R03.**	

4. 2.3 and 2.4 (and 9.6.1) In terms of anchor capacity requirements there is a significant departure in principal from Rev 1, as the capacity of the clump weights is now being defined in Rev 2 by the ULS condition not ALS. Design and operational optimisation needs to be seen as there is no defined anchor capacity.	**As a heavily monitored research and development project it is more economic and achievable to propose an operational solution for chain clumps which reduced their size by linking them as described in these sections. By linking them the capacity of the anchor in the failed leg can be utilised for the leg that has not failed.** **It was considered that no operational optimisation is required because this solution is quite simple. But please advise if this solution requires some further clarification.**  **Additional to considerations of risk, as per Figure 13-6, even with the worst single failure of the attachment point and, combined with the umbilical weak link proposal there remains no risk to EMEC assets or other device assets. This point is emphasised in**	

Innovation Centre - Orkney
Hatston Pier Road
Kirkwall
Orkney
KW15 1ZL
United Kingdom
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	the two drawings below used within the NSRA application documentation.
	
	Anchor capacity is as defined in Section 2.3, 2.4 and 9.6.1, the only chain being subject to the procurement process. If gravity clumps are within the project budget a revision will be made based on a revised friction coefficient.
	
	• **Anchor**
	    o The device is connected to the seabed using four Chain Clump Weights with a total capacity (wet weight) as follows:
	        ▪ NW – 90 Te
	        ▪ NE – 161 Te
	        ▪ SE – 163 Te
	        ▪ SW – 137 Te	

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Hatston Pier Road
Kirkwall
Orkney
KW15 1ZL
United Kingdom
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Figure 0-1 - TDK-MAG-MOOR-DWG-003-NSRA - The hatched area of this drawing shows the maximum possible excursion of the device based on the worst single failure of the any mooring component

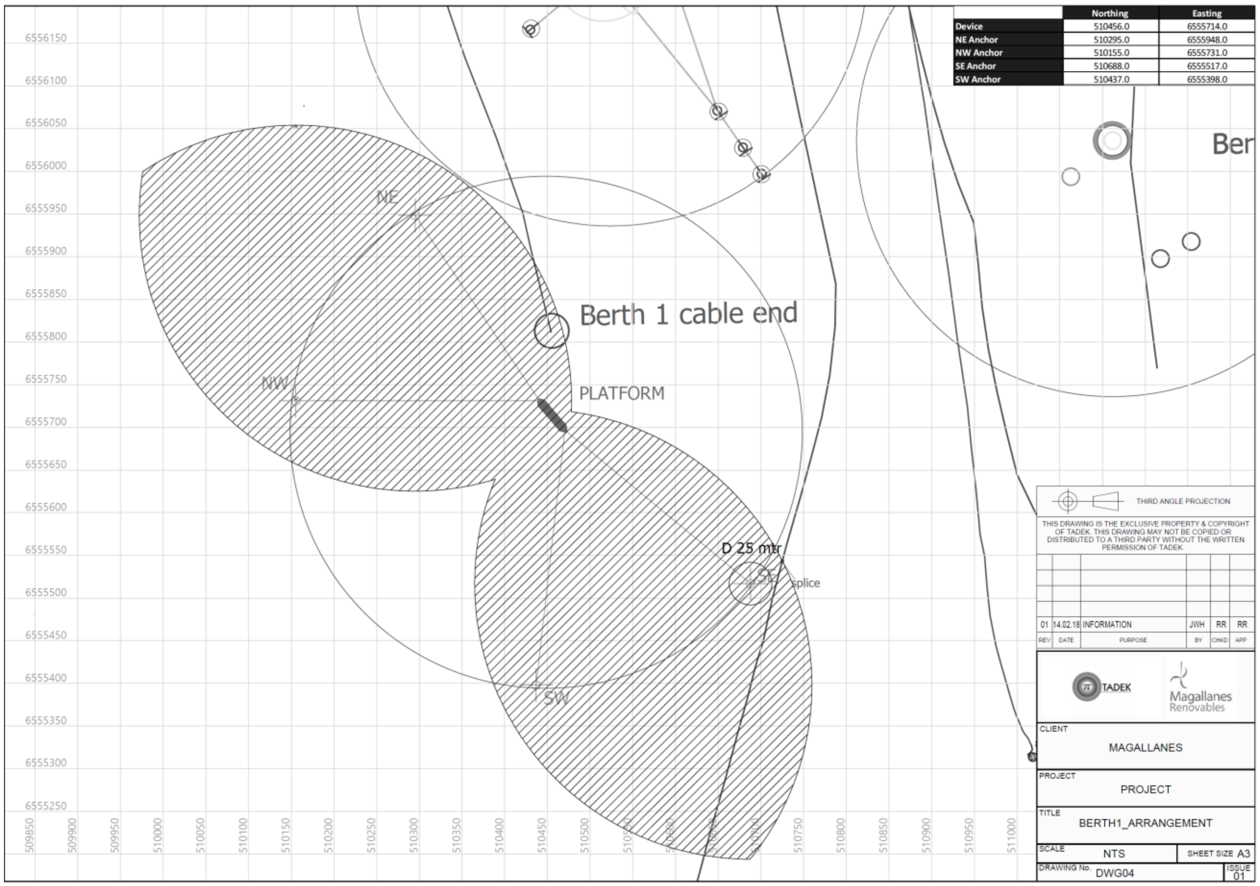

Figure 0-2 - TDK-MAG-MOOR-DWG-003-NSRA – Detail - The hatched area of this drawing shows the maximum possible excursion of the device based on the worst single failure of the any mooring component

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Hatston Pier Road
Kirkwall
Orkney
KW15 1ZL
United Kingdom
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Section 6

5. Does the mooring methodology accurately reflect the process that has been followed with the optimised mooring system? (ALS sims) See Q 2 also	**Yes**	

Section 9

6. Fig 9.7 – What does the white arrow represent it does not seem to correlate with any directional information provided? 7. Table 9.4 this requires updating with modifications	**The white arrow represents the diameter of the mooring spread. The white arrow has now been changed to red and made horizontal to avoid confusion.** **Table 9-4 has now been updated**	

Section 14

8. 14.4 Based on the information we have Item 1 is not acceptable. Item 3 could take the form of a cement box around the appropriate area, either way some evidence of improved strength should be provided	**The use of the special shackle connection construction presented in Figure 14-15 in combination with the R02 mooring design brings the 'bending moment on the mooring eye' down by a factor of around 2.5 compared to the initial assessment. From our previous FE calculations it is clear that the high stresses inside the hull only occur due to the bending moment introduced by severe side forces. The stresses were only just above the yield stress and only in a few nodes. Since the new**	

	design causes much lower bending moments the stresses will be very far below yield stress for all load cases.	

PART 2

Further comments to Magallanes Response to Briefing Note 3 included as Annex B in document TDK-MAG-MOOR-TR-001.			
Reference Number from Briefing Note 3	**Outstanding Comments**	**Response**	**Closed out?**
1 to 32.		All responses accepted	Yes

Further comments to Magallanes Response to Briefing Note 4 included as Annex B in document TDK-MAG-MOOR-TR-001.			
Reference Number from Briefing Note 4	**Outstanding Comments**	**Response**	**Closed out?**
1 to 17 and 19.		All responses accepted	Yes

Innovation Centre - Orkney
Hatston Pier Road
Kirkwall
Orkney
KW15 1ZL
United Kingdom
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18		A complete operational risk assessment will be a condition of compliance with TPV	Yes – subject to sighting prior to deployment

Further comments to Magallanes Response to Briefing Note 5 included as Annex B in document TDK-MAG-MOOR-TR-001.			
Reference Number from Briefing Note 5	**Outstanding Comments**	**Response**	**Closed out?**
1 to 8		All responses accepted	Yes

Innovation Centre - Orkney
Hatston Pier Road
Kirkwall
Orkney
KW15 1ZL
United Kingdom
www.orcadesmarine.co.uk

APPENDIX N – TPV CORRESPONDENCE REV 3.0

Innovation Centre - Orkney
Hatston Pier Road
Kirkwall
Orkney
KW15 1ZL
United Kingdom
www.orcadesmarine.co.uk

TPV of "ATIR - Magallanes - Basis of Design for Mooring of a floating tidal energy converter at EMEC				
Comments by		Checked by	Authorized by	Date (original)
D Thomson		AT	David Thomson	7th April , 2018
Briefing Number	Issue Date	Revision Details/Content		Distribution List Index Number
Rev 7.0	07.04.2018	*TDK-MAG-MOOR-TR-001-R03*		1,2,3
Distribution List Key				
Company		Responsible Person		Distribution List Index Number
Tadek Offshore		Rupert Raymond		1
Magallanes Renovables		Pablo Mansilla		2
Magallanes Renovables		Marta Rivas		3

Content

Part 1

Is the response to the submission of the third revision Tadek document *TDK-MAG-MOOR-TR-001-R03. TDK-MAG-MOOR-TR-001-R02* and the new information contained within

Part 2

The *Appendix J of TDK-MAG-MOOR-TR-001-R03* compiles responses to Briefing Note 6 previously issued by the TPV Provider, this Section 2 completes the "close out" with comments where appropriate.

PART 1

No further comments.

ORCADES MARINE
Management Consultants Ltd

Innovation Centre - Orkney
Hatston Pier Road
Kirkwall
Orkney
KW15 1ZL
United Kingdom
www.orcadesmarine.co.uk

PART 2
Section 1

Further comments to Magallanes Response to Briefing Note 6 included as Appendix M in document TDK-MAG-MOOR-TR-001-R03.		
Comments	**Response**	**Closed Out YES/NO**
1. 1.3.1 the approximated fatigue calculations we have used are indicative of significant potential for early fatigue failure on the main shackle. This concern has not been specifically addressed. An intensive inspection regime in the early days of deployment may be accepted but we would like clarification on your approach to this.	It is accepted that the structural checks that were carried out were based on assumptions made at the time and in the absence of accurate information. As was stated in the introductory email on 19th March "There are a number of assumptions in the TPV structural report but never the less it does indicate a high likelihood of early failure of the attachment point pad eye and surrounding steel, which will need to be addressed". The purpose of the rough calculations that were sent in the unchecked form (in an effort to be expeditious) was to highlight the concerns that we had. This has been acknowledged and addressed by the change in the design of the pad eye arrangement and further mitigation to be provided in the form of a diligent inspection regime in the specific area.	**YES**
2. 1.3.2 Do the modifications to the mooring affect the geometry in any conditions and can you please confirm that the optimised mooring system has been re-modelled in Orcaflex, and the results from there, are that shown in Rev 2 (incl ALS 13.3)		**YES**
3. 1.4 change from chain to solid steel will change for coefficient of friction. Please confirm this will be taken into account in the optimisation		**YES**

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Management Consultants Ltd

Innovation Centre - Orkney
Hatston Pier Road
Kirkwall
Orkney
KW15 1ZL
United Kingdom
www.orcadesmarine.co.uk

Section 2		
4. 2.1 Fig 2.1 and Fig 9.1 do these still represent the plan view of the geometry with the mooring modifications?		**YES**
5. 2.3 and 2.4 (and 9.6.1) In terms of anchor capacity requirements there is a significant departure in principal from Rev 1, as the capacity of the clump weights is now being defined in Rev 2 by the ULS condition not ALS. Design and operational optimisation needs to be seen as there is no defined anchor capacity.	Clarified and accepted	**YES**
Section 6		
6. Does the mooring methodology accurately reflect the process that has been followed with the optimised mooring system? (ALS sims) See Q 2 also		**YES**
Section 9		
7. Fig 9.7 – What does the white arrow represent it does not seem to correlate with any directional information provided?		**YES**
8. Table 9.4 this requires updating with modifications		**YES**

Orcades Marine Management Consultants Ltd

Innovation Centre - Orkney
Hatston Pier Road
Kirkwall
Orkney
KW15 1ZL
United Kingdom
www.orcadesmarine.co.uk

Section 14

9. 14.4 Based on the information we have Item 1 is not acceptable. Item 3 could take the form of a cement box around the appropriate area, either way some evidence of improved strength should be provided	The description of the revised structural design change (replacement of conventional shackle with appurtenance) and results of the Clients FE calculations is accepted.	**YES**