Assessing feasible mooring technologies for a Demonstrator in the Bornholm Basin as restricted to the modes of operation and limitations for the Demonstrator

Technical report no.4

Holger Eriksson &
Thomas Kullander

C98
Rapport
Gothenburg 2013

Department of Earth Sciences
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Department of Earth Sciences
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Abstract

This report recommends a mooring system that is feasible for a Demonstrator floating wind turbine and pumping unit located in the Bornholm Basin of the Baltic Proper. The mooring system is based on proven technology from the Hywind I design which has shown to be safe, reliable, durable, robust, clean and cost-efficient.

The recommendation is applicable for the proposed locations presented in Technical Report no. 2 (Ödalen and Stigebrandt, 2013) of the BOX-WIN series of reports, where water depth is approximately 100 meters and sea-bed soil is pre-dominantly clay and sand.

A traditional three-point spread mooring system is recommended to be pre-laid out on site in rotational symmetrical pattern with crowfoot of a two toes steel wire rope attached to permanent pad eyes on the floater. The three mooring lines are recommended to be chain at sea floor plus steel wire ropes atop and drag embedment anchors penetrating into the sea-bed.

Installation and operation of the mooring system will use existing and proven technology presently used on marine floating installations such as floating wind turbines, load-out buoys and other offshore units.

Sammanfattning

Denna rapport rekommenderar ett förankringssystem passande för en Demonstrator som är ett flytande vindkraftverk med pumpenhet placerad i Bornholmsbassängen i södra Östersjön. Förankringssystemet bygger på beprövad teknik från det flytande vindkraftverket Hywind I vilken har visat sig vara säker, pålitlig, robust och kostnadseffektiv, samt ha liten inverkan på botten.

Rekommendationen är tillämplig för de föreslagna platserna presenterade i Technical Report no. 2 (Ödalen och Stigebrandt, 2013) i rapportserien från BOX-WIN, där vattendjupet är ungefär 100 meter och havsbottnen består huvudsakligen av lera och sand.

Ett traditionellt tre-punkters förankringssystem rekommenderas läggas ut i förväg i ett rotationssymetriskt mönster på havsbotten runt Demonstratorn för att senare vid installationen anslutas via hanfötter till permanenta fästöglor fastsatta på den flytande enheten. De tre förankringarna rekommenderas bestå av bottenpenetrerande ankare, kätting på sjöbotten och stålwire i den övre delen.

Installation och drift av förankringssystemet kommer att utnyttja befintlig och beprövad teknik använd på marina flytande anläggningar såsom flytande vindkraftverk, utlastningsbojar och andra flytande offshorekonstruktioner.

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Preface

In 2008, Formas and Naturvårdsverket (Swedish EPA) announced available funding for research on the possibility to use deepwater oxidation as a mean to combat eutrophication in the Baltic Sea. Two projects, BOX, "Baltic deepwater OXygenation" and PROPPEN were funded at the end of December 2008. These projects have shown that phosphorus leakage from anoxic bottoms in small coastal basins may be stopped by oxygenation. BOX has shown that this also is true for the Baltic proper. The BOX-WIN project "winddriven oxygenation by pumping and generation of electrical power" builds on BOX.

Results from the BOX-WIN project will be presented in a series of reports from the Department of Earth Sciences at University of Gothenburg. A wide range of subjects are covered by BOX-WIN. Technological, environmental, economical and legal facts and circumstances must be considered to develop and locate a full-scale Demonstrator composed of a self-supporting, floating wind turbine unit with a generator producing electric power for deepwater oxygenation by pumping and for delivery to the grid. The Demonstrator will be developed for the Bornholm Basin, which at times has anoxic water in its deepest parts. The Demonstrator developed by BOX-WIN will hopefully be built to conduct tests in the Bornholm Basin. This would be an important step towards installation of a regional system of full-scale floating wind turbine units with pumps in the Bornholm Basin. An updated list of BOX-WIN reports is included at the end of the report.

The present report, "BOX-WIN Technical report no. 4 - Assessing feasible mooring technologies for a Demonstrator in the Bornholm Basin as restricted to the modes of operation and limitations for the Demonstrator", is written by Holger Eriksson and Thomas Kullander. The work is funded by the Swedish Agency for Marine and Water Management.

Gothenburg 19 February 2013

Anders Stigebrandt

1. Introduction

This report serves the purpose to envisage different prevailing mooring technologies which are safe, reliable, robust, clean and cost-efficient and propose a recommendation of these for basic application to a Demonstrator. The Demonstrator will be a floating wind turbine and pumping unit, located on an assigned location in the Bornholm Basin of the Baltic proper. The recommendation is applicable for the proposed locations presented in Technical Report no. 2[1] of the BOX-WIN series of reports, where water depth is approximately 100 meters and sea-bed soil is pre-dominantly clay and sand.

This feasibility study of a Demonstrator is based on the proven design of the Floating Wind Turbine Unit (FWTU) named Hywind, which has been moored in the Norwegian Sea west of Bergen, Norway at about 500 meters of water depth and operated continuously since 2009. The Hywind FWTU is referred to as Hywind I herein. Its design has been modified to accommodate a water pumping device for midwater ventilation. Further, some evolving FWTU technologies of the Hywind II concept have been assessed by keen assistance of Statoil A/S, the owner of the Hywind.

The main functions of a mooring system for floating offshore units are to maintain stationary position and provide hydrodynamic damping of vessel motion. Such a floater often connects to the seafloor also by its dynamic oil and gas risers, control umbilicals and power cables which are hung off in a wet position onto the lower hull, or in a dry position onto the upper hull, and basically attached by a fixed or flexible connection to the sea bottom installation. These links and connections will displace from each other by impact of hydrodynamic forces and obtain variable loads which are attributable to high ultimate stress and material fatigue. To restrict the hydrodynamic motion and maintain the design limit of links and connections, geostationary control is generally required both horizontally and vertically. First order heave motion is also important to control, particularly for slender units with small water-plane area which are prone to vertical oscillation, as for Hywind and the like. The damping provided by means of the mooring system combines with that of the submerged substructure of the unit and depends on the wind, waves and current; where the spring constant of the mooring system composes the submerged body mass and the configuration, mass, elasticity and pre-tension of the mooring lines.

Additional functions of the mooring system of the Demonstrator are to prevent the substructure to rotate due to gyration, which is generated by the wind turbine blades in operation and whose effect is resolved by Hywind, and to resist horizontal oscillation and retain position at moderate ice-drift.

Hydrodynamic analysis, mooring calculation and ice calculation are performed in the Basic Design phase. Illustrations of offshore mooring systems are shown in Figure 1.

Figure 1. Offshore Mooring Systems

2. Comparative Design Data for a Demonstrator

Design data for mooring of a Demonstrator are given in Table 1 together with design data of Hywind I and II. [2,3]

Table 1. Design Data used for various FWTU (approximate figures).

FWTU	Demonstrator	Hywind I	Hywind II (concept)	OC3 – Hywind (prospect)
Displacement (ton)	5,500	5,000	7,500	5,500
Water Depth (m)	100	500	300	320
Draught (m)	85	120	80	120
Diameter in waterline (m)	6,5	6,5	6,5	6,5
Location (actual or proposed)	Baltic Sea: Bornholm Basin	Norwegian Sea: West of Bergen	Atlantic Ocean: Main State, US North Sea: Scotland Continental shelf	Seven Seas: World wide
Mooring Pattern	3 - spread	3 - spread	3 - spread	3 - spread
Nacelle Height above waterline (m)	80 - 100	100	100	100
Effect (MW)	1,5 – 3,0	2,3	3,0	5,0

3. Comparison of systems, components and methods usable for mooring of a Demonstrator

Common mooring systems, mooring lines, anchors, attachments and installation methods are compared as per their prominent features, the pros and cons of which are presented herein to form a recommendation of application for one Demonstrator of type Hywind I or II. It is to be noted that, should multiple pumping units of type Hywind I or II be arranged in a future pumping facility farm, another mooring system may be found more suitable than the one recommended in this report.

A general mooring system comprises mooring lines attached to anchors laid out on the seafloor and penetrating into the sea bed, and hang-up devices attached to the floater. Within the offshore technology, different types exist in various configurations of mooring system, mooring lines, anchors, hang-up devices and installation methods. Type and configuration are most effective for a particular condition and these primarily depend on the displacement and shape of the submerged body of the floater, the area projected to the wind and the size of the splash zone, the water depth at the location and the seabed characteristics. Forces, displacements and motions are primarily determined as calculated for the mooring system and based on the size and streamlined shape of the floater to fend-off harsh environmental loads excited from gale wind, rough sea, strong current and severe ice drift or large ice boulders. Mooring lines and hang-up locations are then optimized to meet the design motion limitations as specified for the floater. Finally, the sea-bed characteristics provide input to the choice of anchors.

Both Hywind I and II basically comprise a central vertical steel cylinder, which is partially filled with water ballast and rock, extending from the baseline all the way up to the nacelle but of considerably slender shape; thus constituting a structurally integrated design of length equal to the sum of floater draught and height from the waterline to the nacelle, and width equal to the diameter of the cylinder. At about half of the draught, the mooring lines of a three-point mooring spread system are extended to three hang-up devices designed as pad eyes welded to the outer shell of the cylinder. Each extension is provided by means of a crowfoot which comprises two wires, each attached to a pad eye in one end and in the other end to a mooring line in common to both wires. Pad eyes are positioned as to prevent rotation of the floater due to gyration which is introduced by the wind turbine blades in operation. The mooring lines are all wire, except for at a distance from the sea-floor, where each mooring wire is shackled to a chain extending all the way to the attachment of an anchor resting on the seafloor.

Information about software and Hywind specifications is confidential and not presented in this report. For general mooring system information, see Vryhof Anchors BV anchor manual.[4]

The Demonstrator features some design characteristics (c1 - c5) which are significant to the choice of principal mooring system, spread pattern, anchors, mooring lines and hang-up system:

c1. There is a restriction on twist around the centreline of the Demonstrator that is necessary to prevent torsion of the floater due to gyration, which is the spinning effect from the wind turbine blades in operation, i.e. only small angles of approximately maximum 5 degrees of torsional deflection are allowed,

c2. There is no connection point on the seafloor that must be aligned with the centreline of the Demonstrator, i.e. the Demonstrator is free to deviate horizontally somewhat from its geostationary mooring position,

c3. There is no connection point on the seafloor that must maintain the vertical distance relative to the Demonstrator, i.e. the Demonstrator is free to deviate vertically somewhat from its geostationary mooring position as long as the necessary seafloor margin is kept,

c4. All seafloor connections are attached to the floater in between the pumping devices and arranged not to interfere with each other,

c5. All seafloor connections are flexible and designed to accommodate the above deviations. For this reason, the dynamic power cable may be arranged in a lazy S, i.e. supported by a separate submerged body at about 50 m of water depth that is floating between the Demonstrator and the static power cable connection on the sea floor.

The set-off and heave motion are the effects of the environmental loads to the Demonstrator and the response from these are materialized as restoring forces from the mooring system. So a gale will set-off the Demonstrator approximately maximum 10 m, introduce vertical heave motion of approximately maximum 2 m and cause the Demonstrator to incline at angle of approximately maximum 7 degrees to the vertical. These figures will be detailed in the Basic Design for different loading conditions.

3.1 Mooring Systems

For mooring of the Demonstrator, two principal offshore mooring systems are compared:

– Catenary Mooring, comprising several mooring lines which are catenary suspended and spread out omnidirectionally from the centreline of the floater in a pattern of rotational symmetry or symmetry around the line of predominant environmental load direction,

- Taut Line Mooring, comprising several mooring lines which are vertical or inclined connecting the floater with the seafloor by means of pretension introduced by pulling the floater down into the water.

The pros and cons of the principle offshore mooring systems are compared in Table 2.[5, 6, 7,8]

Table 2. Pros and cons for principal offshore mooring systems.

Principal Mooring Systems	Pros	Cons
Catenary Mooring	Proven technology for FWTU's.	Limited degree of reduction of vertical motion of the floater.
Taut Line Mooring	Almost no vertical motion and small horizontal of the floater.	Unproven technology for FTWU's. Extensive sea-floor interference and expensive piling for anchors. Costly installation.

For the Demonstrator, the design characteristics (c1 – c5) and pros and cons of Table 2 certainly points to a catenary mooring system as the most applicable one to choose for a principal mooring system. To emphasize, a catenary mooring system for the Demonstrator:

- Does not introduce a design which is fixed to the sea bottom but a floater, and thus the Demonstrator can be removed off location and need not be classified as a permanent installation. In offshore, permanent installations are often ruled by land authorities who exercise a national, complex and completely different legal framework than that of sea authorities, who tend to rely on international standards and marine conventions which are uniform and apt to serve fleets of mobile units,

- Does not introduce heavy concrete or steel foundations on the seafloor as required for taut line mooring systems, and thus the environmental impact of the seabed is reduced,

- Does not rely on a few international specialized installation vessels with expensive slots not easily available, but on Swedish supply vessels which are relatively cheap and easily available,

- Does not imply new mooring designs that are new to Swedish offshore companies, but uses proven technology and methods already used by them.

3.2 Spread Patterns of Catenary Mooring System

Different mooring spread patterns can generally be used to make stable the submerged body of the unit and to generate small motions of the unit with a minimum of rotation around the vertical centreline for a unit of Hywind type. Three types of catenary mooring line spreads are compared (see Table 3):

- Rotational Symmetrical, using several single lines,
- Rotational Symmetrical, using several single lines with one crowfoot each. Each mooring line ends in a crowfoot and makes up for one Y-shaped connection, where the mooring line corresponds to the stem and the crowfoot the diagonals of the capital letter Y,
- Rotational Unsymmetrical, using several single lines.

Table 3. Pros and cons for catenary mooring spread patterns.

Mooring Spread Pattern	Pros	Cons
Rotational Symmetrical, Single Lines	Equalized forces around the structure. Easy to install.	Limited effect on the yaw stiffness of the unit.
Rotational Symmetrical, Single Lines and Crowfoot	Increased effect on the yaw stiffness of the unit.	Requires an additional connector under water. More complicated to know and adjust the tension of the mooring lines.
Rotational Unsymmetrical	Not more than three (3) single mooring lines are required.	The location of hang-up points may interfere with the pumps. Requires asymmetric design of the submerged body of the unit.

For the Demonstrator, the design characteristics (c1 – c5) and pros and cons of Table 3 point to a mooring system of spread pattern which is rotational symmetric and connected to a crowfoot as the most applicable. To emphasize, a rotational symmetrical spread and crowfoot system for the Demonstrator:

– Prevents twisting of the Demonstrator which is necessary to minimize wear and tear of the connection of the dynamic cable to the floater, the buoyant body and the seafloor connection of the static cable,

– Resists environmental loads equally well from all directions, that is typical for water areas without a pre-dominant direction of significant loads and also applicable for the location in the Bornholm Basin,

– Prevents twisting of the Demonstrator by use of crowfoots to redistribute the mooring line loads, i.e. unevenly in normal conditions and evenly in survival conditions, and in a combination thereof. So in normal operation, when the turbine blades are rotating, a moment of gyration is created around the centreline of the Demonstrator that is counteracted by the tension introduced in one the two diagonals of each crowfoot, while the other one is slack. In survival conditions, when the wind turbine is shut down due to gale wind, no moment of gyration exists but large tension in the mooring lines occurs in both diagonals of the crowfoot.

3.3 Anchors

Four types of offshore anchors are compared:

– Drag Embedment Anchors (DEA), comprising a main shank and at least one fluke which are laid on the sea-floor to penetrate the sea floor, either partly of fully, when dragged horizontally by the mooring lines (see Figure 2). The holding capacity is generated by the resistance of the soil in front of the anchor. This is the most popular type of anchoring point available today,

– Driven Pile Anchors (DPA), comprising a long hollow tube which is piled vertically by an external hammer or the like into the sea bed and fixed on site by friction of the soil along the pile and lateral soil resistance,

– Suction Pile Anchors (SPA), comprising a long steel tube with much larger diameter than the DPA; forming a closed compartment which is piled vertically by an external pump into the sea-bed and the compartment emptied from air and thus fixed on site by vacuum forces to the sea-bed (see Figure 3),

– Vertical Loaded Anchor (VLA), comprising a main shank and several foldable flukes which penetrate the sea floor when dragged horizontally and vertically by the mooring lines (see Figure 4). This is similar to the DEA, but the VLA penetrates much deeper.

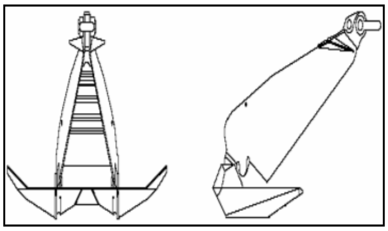

Figure 2. Drag Embedment Anchor

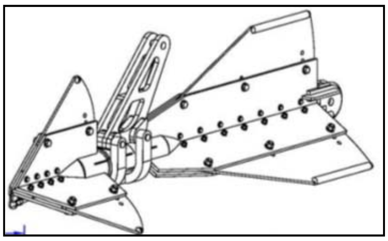

Figure 4. Vertical Loaded Anchor

Figure 3. Suction Pile Anchor

In general, the holding capacity of an anchor combines with the anchor mass, the mass of soil in the failure wedge, the friction of soil in the failure wedge along fracture lines, the friction between fluke surface and soil (fluke area), the bearing capacity of shank and mooring line and the friction between mooring line and soil.

The pros and cons of the four different anchor types are presented in Table 4.

The design characteristics (c1 – c5) and pros and cons of Table 4 points to a Drag Embedment Anchor as the most applicable one to choose for the Demonstrator.

Traditional anchors of DEA type tend to plough themselves down into the sea-bed by the horizontal pulling loads introduced in the mooring lines when these are tied up by increased tension from anchor winches or vessel set-off, while the point of attachment of the line to the shank tends to remain in the sea bed soil somewhat below the sea floor, which increases the holding power of the anchor. Although increased holding power applies also to piled anchors of DPA type when horizontal loads are introduced in the mooring lines, because the point of attachment to the line is located at some meters below the sea floor, these are considerably more expensive to install. Some piles of DPA or SPA type, which are subject to vertical loads only, are designed with the point at attachment to the line being located above the seafloor, i.e. on top of the pile; however, this feature is not required since the mooring system of the Demonstrator is not designed to take vertical loads. [9]

To emphasize, Drag Embedment Anchors for the Demonstrator:

- Are cheaply and easily installed and retrieved, particularly in shallow water depths of about 100 m,
- Possess good penetration characteristics for clay and sand soil, as reported from the Bornholm Basin.

Table 4. Pros and cons for offshore anchor types.

Anchor types	Pros	Cons
Drag Embedment Anchor (DEA)	Proven technology used on most floating drilling, production, accommodation and FSO-units offshore. Very well suited to resist large horizontal loads excited by the floater. Easily retrievable.	Exact anchor position cannot be guaranteed. Cannot always take vertical loads.
Driven Pile Anchor (DPA)	Exact position of anchor location. High holding power in most soil conditions so nearby installations can use the same anchor. Can withstand both horizontal and vertical loads.	More costly installation operation compared to DEA. Normally requires a larger anchoring vessel and more equipment.
Suction Pile Anchor (SPA)	Exact position of anchor location. High holding power in most soil conditions so nearby installations can use the same anchor. Can withstand both horizontal and vertical loads.	More costly installation operation compared to DEA. Normally requires a larger anchoring vessel and more equipment. Large and bulky to handle.
Vertical Loaded Anchor (VLA)	Proven technology used on most drilling rigs offshore. Can withstand both horizontal and vertical loads.	Exact position cannot be guaranteed.

3.4 Mooring Lines

Mooring line is the common nominator of all types and materials of ropes and chains and the combinations thereof used to connect the floater to the seafloor. While chain and wire ropes are made of steel, synthetic fibre ropes are often made of polyester or polyethylene. Design and composition depend on a number of technical parameters such as the type of mooring system, seabed characteristics, water depth, excited loads and required motion characteristics of the floater.

During operation and depending on the weather and design conditions, the mooring force continuously varies in the mooring system which imposes the tying up and slackening of the mooring lines. The angle of point of attachment of the line to the seafloor will then also vary, with the result that the sea floor is subject to mechanical wear and tear by the mooring lines. In this respect, chain is more resistant to sea floor wearing than ropes.

A mooring line of wire rope has a smaller diameter and less friction to the seafloor than a chain and for this reason, penetrates deeper in the soil compared to a chain. Additional soil penetration by the wire rope means increased soil penetration by the anchor, which in turn increases the holding power of the anchor. However, the holding capacity of a chain solely (i.e. excluding the anchor) is larger than that of a rope, which is due to larger friction of a chain in and on the seabed. The reduced penetration of a chain is caused by higher lateral resistance (penetration resistance) along the chain mooring line. This effect is noticeable in all soil conditions but especially in very soft clay, where very deep penetration damages may develop by use of wire ropes.

Five types of mooring lines are compared in Table 5. It is to be noted that clump weights may optionally be hanged onto the mooring lines to optimize the stiffness of the mooring system.

For the Demonstrator, the design characteristics (c1 – c5) and pros and cons of Table 5 points to a mixed mooring system consisting of chain and wire rope as the most applicable. To emphasize, a chain-wire rope mooring system for the Demonstrator:

- Does not use wire ropes all down to the sea floor in order not to disturb the environment of the seabed, instead the chain will lay down without adverse movement of the bottom sediment,
- Does not use fibre rope since the water depth is only about 100 m and the elasticity of a fibre rope system versus weight is not critical, so a taut line mooring system is not chosen, and the risk of wear and tear of the fibre rope to the sea bottom can be avoided,

– Is not vulnerable to material fatigue of the wire rope since a three-point spread mooring system is designed to take all loads on only one mooring line, i.e. is designed for ultimate load and not fatigue.

Table 5. Pros and cons for offshore mooring line combinations.

Mooring Line	Pros	Cons
Steel Wire Rope (only)	Easy to install. Limited weight. No connection between different materials.	Reduced resistance against wear and tear from long term contact with the seabed. Prone to material fatigue.
Steel Chain, (only)	Easy to install. Can withstand long term contact with the seabed.	Heavy weight. Will not penetrate deep into the soil.
Synthetic Fibre Rope, polyester or polyethylene, (only)	Easy to install. Low weight. No connection between different materials.	No resistance against wear and tear from long term contact with the seabed.
Mixed type, Chain +Wire Rope	Proven design for FWTU's. Maximum flexibility. Reduced weight. Can withstand long term contact with the seabed.	Additional subsea activities during installation may be required. Connector devices may be required.
Mixed type, Chain + Synthetic Fibre Rope	Maximum flexibility. Minimum weight. Can withstand long term contact with the seabed.	Additional subsea activities during installation may be required. Connector devices may be required.

3.5 Hang-Up System

Two methods for attaching the mooring system to the floater have been compared:

– Fixed Tension, which does not allow the mooring lines to be tightened or slackened by other means than a change of draught,

– Variable Tension, which allows the mooring lines to be tightened and slackened by means of anchor winches and without a change of draught.

Table 6. Pros and cons for hang-up systems.

Hang-Up System	Pros	Cons
Fixed Tension	Easy installation and hook-up. Operation mode not required. Inexpensive. Only Pad Eyes are necessary, fairleads are not required.	Cannot adjust tension in the mooring lines after installation. Cannot adjust line tension to match a new vessel draught or changed wind and wave loads.
Variable Tension	Mooring lines can be tied-up and slackened to match a new vessel draught or changed wind and wave loads. Allows for exact positioning of the unit. Allows movement of the catenary fatigue point for wire ropes.	Expensive. Fairleads necessary. Anchor winches are required. Deck area needed for operation of anchor winches.

For the Demonstrator, the design characteristics (c1 – c5) and pros and cons of Table 6 points to a fixed tension mooring system as the most applicable. To emphasize, a fixed tension mooring system for the Demonstrator:

– Is cheap to install and design and need not be operated, which allows the Demonstrator to be unmanned,

- Does not allow the draught to be considerably changed without affecting the tension of the mooring lines. However, the draught might be slightly changed by simultaneously changing the mooring line tension. For example, in an ice drift or iciness condition, the draught may be slightly increased to maintain stability at the price of less tension and stiffness in the mooring system which, in result thereof, will increase the Demonstrator set-off. This will be calculated in the Basic Design phase,

- Does require the vertical position of the hang-up, i.e. the pivot point, to be optimized so as to keep the angle of inclination of the Demonstrator at a minimum. The environmental forces on the submerged body (current and wave loads) will have to be balanced with those of the splash zone (waves and ice loads) and the upper body (wind and iciness),

- Does not allow tensioning of the mooring lines in order to redistribute the mooring line forces at gale wind, which is anyway not needed for a three-point spread system where one mooring line is designed to take on all environmental loads from one direction,

- Does not allow for fatigue redistribution of wire ropes, which is anyway not required for shallow waters since short wire ropes might be easier and cheaper to replace by new ones,

- Does allow for clump weights to be hanged onto the connections between mooring lines and the crowfoots, which will increase the stiffness of the mooring system.

3.6 Installation

Two methods for mooring system installation have been compared:

- Pre-set, where anchors and mooring lines are pre-laid out and simply hooked up by supply vessels at the time for the installation (see Figure 5),

- Concurrent, where anchors are laid out with mooring lines attached to them and hanged up onto the unit.

These are presented in Table 7.

Table 7. Pros and cons for methods of mooring system installation.

Installation Methods	Pros	Cons
Pre-set	A longer weather window becomes available for installation, Limited interaction with the Demonstrator.	Extended installation time.
Concurrent	Almost all activities on site can be performed at the same time, No extra transfers and transports are required.	Too many vessels at site during hook-up.

For the Demonstrator, the pros and cons of Table 7 indicate that installation of a pre-set mooring system is the most applicable. To emphasize, a pre-set mooring system for the Demonstrator:

– Does allow for a longer weather window which is less prone to delays and less risky to interfere with installation operations and operators.

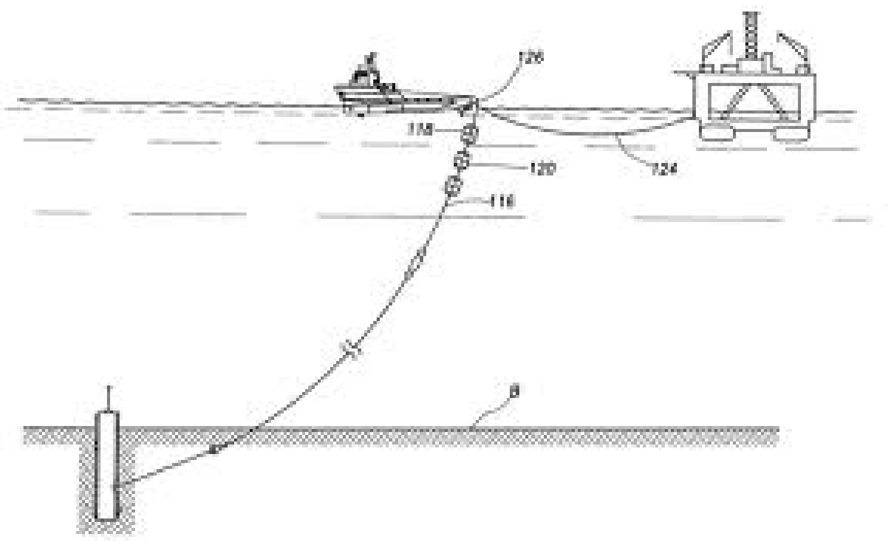

Figure 5. Pre-set Mooring System (DPA or SPA)

4. Recommendation

In accordance with the evaluation of pros and cons in the previous sections, this report recommends the mooring system of the Demonstrator to be designed and based on the same principal mooring system that is used for the Hywind I:

Mooring system	: Catenary three-point Spread
Pattern	: Rotational symmetrical with Crowfoot
Anchors	: Drag Embedment Anchor
Mooring Line	: Chain (sea floor) + Steel Wire Rope (top)
Hang-Up	: Fixed tension
Installation Method	: Pre-set

It is to be noted that should multiple pumping units of type Hywind I or II be arranged in a future pumping facility farm, another mooring system may be found more suitable than the one recommended in this report.

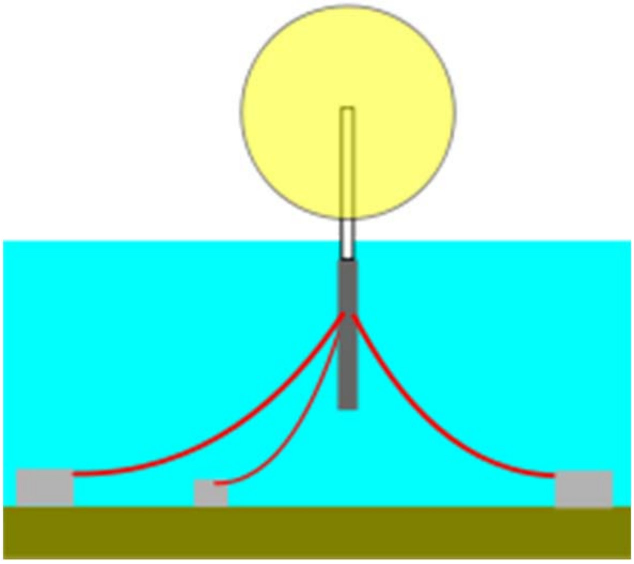

Figure 6. Proposed Mooring of the Demonstrator

5. Acknowledgements

This work was funded by the Swedish Agency for Marine and Water Management. Statoil ASA Department for Offshore Wind and MoorLink AB are acknowledged for providing important data for this study.

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