PivotBuoy

An Advanced System for Cost-effective and Reliable Mooring, Connection, Installation & Operation of Floating Wind

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D6.1: Identification of failure modes and initial reliability, health & safety and environmental assessment of the PivotBuoy system

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Dissemination Level		
PU	Public	X
PP	Restricted to other programme participants (including the Commission Services)	
RE	Restricted to a group specified by the consortium (including Commission Services)	
CO	Confidential, only for members of the consortium (including Commission Services)	

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Document History

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29/08/2019	0.1	First release – Consortium Internal Review
12/09/2019	0.2	Internal review by X1 Wind
20/09/2019	1.0	Final version
23/09/2019	1.1	Final version for release

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1 EXECUTIVE SUMMARY

This report is the initial deliverable of Task 6.1 (Hazard and Reliability Aspects), Task 6.2 (Health & Safety Aspects) and Task 6.3 (Environmental Aspects). It presents the initial HAZard IDentification (HAZID) and potential failure modes, reliability, health and safety and environmental assessment of the PivotBuoy system. The initial assessments presented herein are based primarily on an initial technology assessment and Failure Mode, Effects and Criticality Analysis (FMECA), which were conducted with the participation of subject matter experts from the PivotBuoy consortium members.

This report is produced with the objective to identify and to assess the risks so that they can be managed effectively during the further design process. The selected processes focus on the specific risks associated with each of the system main components and sub-components throughout the system lifecycle; i.e. design, fabrication, installation and operation phases.

Risk to the asset and risk to persons (i.e. health and safety risks) are considered as part of the technology assessment and FMECA with the intention to apply remedial actions early in the design process. An additional desktop assessment has been performed with the specific objective to identify environmental risks.

Detailed risk registers are appendices to this report. They have not been made publicly available for IPR reasons. In case third parties would like to request access to more detailed information the project contact details have been made available at the end of the document.

This report addresses for the technology assessment the PivotBuoy system as per the conceptual design definition (the current design at the time of execution). The FMECA applies to the preliminary design as developed from the conceptual design during the preparation of this initial risk assessment. The process of risk assessment will continue as the design develops further, and the results presented herein will be re-visited and updated (where appropriate) during the detailed design phase. Deliverables D6.2 and D6.3 will present further updates on reliability, health and safety and environmental assessments of the system.

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2 INTRODUCTION

The *PivotBuoy Project: An Advanced System for Cost-effective and Reliable Mooring, Connection, Installation & Operation of Floating Wind* (referred to as PivotBuoy project) is a project that will develop a prototype of the "PivotBuoy" system to demonstrate its potential to reduce the Levelized Cost Of Energy (LCOE) of floating wind. The PivotBuoy is an innovative subsystem that aims to reduce the costs of mooring systems and floating platforms, that allows faster and cheaper installation and that supports a more reliable and sustainable operation. The system will be installed at the PLOCAN test site (Gran Canaria) to validate the concept, by integrating a prototype of the mooring system in a downwind floating platform that will be developed by X1 Wind.

This report documents the work performed to identify the relevant failure modes and the results of an initial reliability, health and safety and environmental risk assessment of the PivotBuoy system. In Figure 1 the concept design is shown as presented at the start of the project, which has formed the basis for the first reliability and risk assessment effort (technology assessment). Since the execution of this initial reliability and risk assessment, the concept design has developed into a preliminary design. A second risk assessment (FMECA) applies to this preliminary design at the time of issue of this document, see Figure 2.

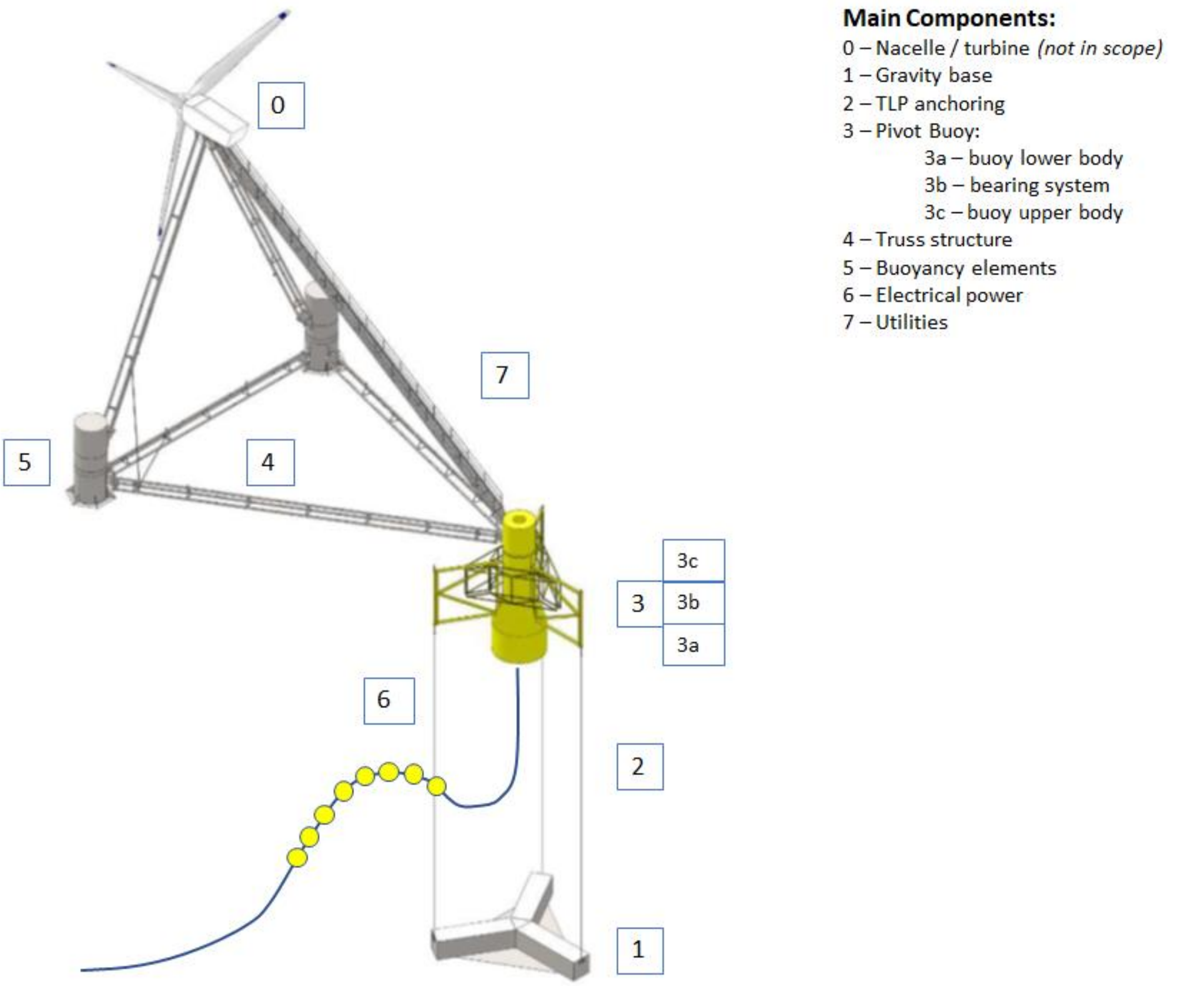

Figure 1. Concept design that has formed the basis for the technology assessment

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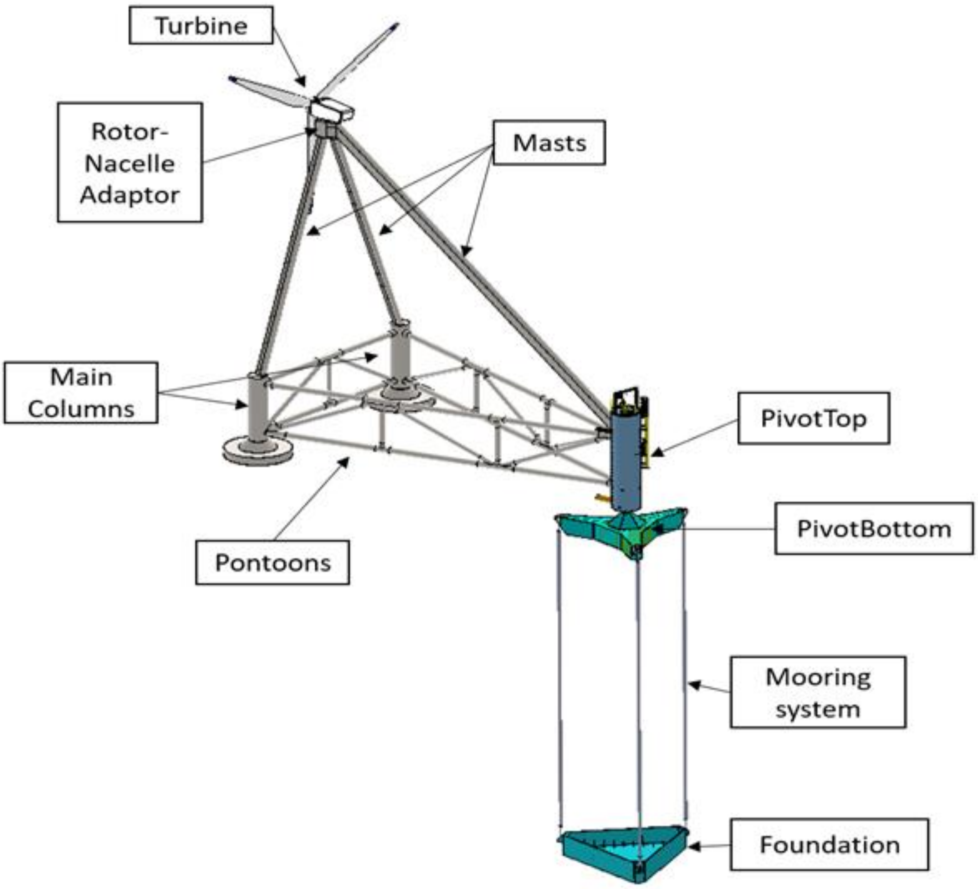

Figure 2. Preliminary design that has formed the basis for the FMECA

The objective for Work Package 6 (Risk Assessment including Reliability, Environment, Health & Safety) activities is to de-risk the system development by identifying critical failure modes and analysing system reliability. The first task (Task 6.1) within this work package is hazard identification and Failure Mode, Effects and Criticality Analysis (FMECA).

The work has started early on during the preliminary design phase by performing a technology assessment for the concept system design following the technology qualification methodology described in DNVGL-RP-A203. This resulted in a technology categorization rating for each major component of the PivotBuoy system.

Based on the preliminary system design as developed from the concept design, an FMECA has been performed to chart the probability of system and component failure modes against the severity of their consequences. The FMECA findings will feed into the detailed design phase so that the identified risks can be addressed and mitigated. Where risks cannot be 'designed out', contingency plans for managing the residual risk will be developed.

There is limited data available in the public domain on risks and failure modes specifically relevant for floating offshore wind systems. This is primarily due to the very limited application of floating wind systems world-wide. However, there is a wealth of experience and data available from cross-cutting fields from other relevant sectors. Regarding the PivotBuoy subsystem and its components, experience from the oil & gas sector and in particular from design, installation and operation of Single Point

Mooring (SPM) systems, Tension-Leg Platforms (TLP) and dynamic riser and cable systems have been applied to identify potential risks. This experience data includes relevant information on failure modes and events.

The process of which the results are presented in this report has been a collaborative effort with input from the consortium members. Sessions have been held as part of planned project meetings, and the minutes of these sessions are available, see [Ref 1] and [Ref 2].

A first session was held in Brussels on the 16th of May 2019 with focus on technology assessment of the PivotBuoy system. This technology assessment addressed the physical components of the system as well as the phases of development and activities.

A second session was held in the X1 Wind offices in Barcelona on the 17th and 18th of July 2019. During this session the component and sub-component definition, failure modes and probability and consequence assignment were discussed and agreed as part of the FMECA process. The performed FMECA is a component focused approach where the different development phases of the project are addressed, where relevant, by assessing the component failure mode multiple times to cover all relevant project phases.

The remainder of this report describes the background for the risk assessment approach taken and the results of the assessments performed.

3 TECHNOLOGY ASSESSMENT PROCESS

Purpose and method

The purpose of a technology assessment is to assess the system components to determine which elements involve aspects of new technology and identify the key challenges and uncertainties. Guidance for this process is provided by DNV-RP-A203 and DNVGL-SE-0422.

A technology assessment starts with the technology composition analysis. In this case the system is divided in components and sub-components, each with a specific function within the PivotBuoy system. Also a split-up in project phases or activities is realized. The next step of the assessment is to determine the novelty of each of the (sub-) components and the uncertainties they represent during each development phase. This is done following the technology assessment approach as described in DNV-RP-A203. Based on this assessment the system design challenges and uncertainties can be identified.

The input for such a technology assessment normally consists of detailed drawings of the items to be qualified, control and safety systems, material specifications, fabrication-, installation-, and maintenance-procedures. In this case, the technology assessment is performed early in the project development to identify critical components and aspects of the PivotBuoy system, so these can be taken into account during the further project development. Detailed drawings, specifications and procedures were not yet available for this initial assessment.

Nevertheless, the method has been applied to gain a better understanding of the considered system, and to identify areas requiring additional attention during further system development. This technology assessment also serves to identify the basis for the next step in project risk identification; namely, the Failure Modes, Effect and Criticality Analyses (FMECA), see Section 4.

Technology categorization

The technology categorization of the system components and development phases is done based on the ranking given in Table 1 (from DNV-RP-A203 / DNVGL-SE-0422).

Table 1: Technology categorization

Area of application	Novelty of technology		
	Proven	Limited field history	New / Unproven
Known	1	2	3
Limited knowledge	2	3	4
New	3	4	4

The resulting categorization values indicate:

1) No new technical uncertainties (proven technology).
2) New technical uncertainties.
3) New technical challenges.
4) Demanding new technical challenges

Based on the assumption that the PivotBuoy system will be developed and compiled from existing technology, the system can be evaluated on two criteria; 1) how mature is the technology itself?, and 2) how similar is the area of application in the PivotBuoy system to the area in which the specific technology component has been developed and applied?

Novelty of the technology refers to the technology itself. Changing components or functions of even well-matured technology will increase uncertainty about the functioning of the technology. This can result in selecting the technology novelty as “limited field history” or even “unproven”.

Application of known and unchanged technology in a new environment will also lead to increased uncertainty. For the technology “limited knowledge” or even “new” can be applicable.

It should be noted that technology class categorization does not consider the consequence of failure. In some cases, failure of a component of Category 4 technology (‘Demanding new technical challenges’) may have little effect on overall system performance, while in other cases the effect of a failure may be catastrophic for overall system integrity. Combination of technology categorization with assessment of consequence of failure can be effective to determine the technology criticality which allows prioritizing of development effort (see Section 4).

Method application

On the 16th of May a session was held in Brussels to perform the technology assessment. Considering the phase of the project at that time, this was done on a high level; i.e. addressing main components with limited sub-components and only main activities during each of the different phases of the project realization.

The technology assessment session was led by INTECSEA and was attended by the following other consortium members:

- X1 WIND
- WAVEC
- PLOCAN
- EDP CNET
- DTU
- DNV GL
- DEGIMA

The minutes of these meetings are available ([Ref 1]).

As a first step, the system was divided into logical, manageable elements. This is done for the physical system itself and for the development phases of the system.

The division of the system into main elements was done as follows:

- Isostatic truss structure
- PivotBuoy lower body
- TLP anchoring
- Electrical power

- SCADA
- Gravity base
- Corrosion protection

Element definition and used terminology are reflecting the concept system design at the time of technology assessment execution.

The division of the life cycle into development phases of the main elements is done as follows:

- Design and procurement
- Fabrication and testing
- Transportation and assembly
- Installation
- Activation and commissioning
- Operation and maintenance
- Decommissioning
- Retrieval and abandonment

The elements for which these life cycle phases are considered are the main components as defined above.

During the session in May 2019, these components and activities were scored on technology status and the application of it. The subject matter experts present during this session, from different fields of expertise (design, fabrication, installation, wind-power, offshore structures, etc) all provided input to identify the project main challenges and uncertainties.

Technology assessment findings – hazard identification (HAZID)

The results of the session are summarized in Table 2 and Table 3.

Table 2: Technology assessment results for components

Technology class	Class definition	Number of components
1	No new technical challenges	46
2	New technical uncertainties	9
3	New technical challenges	4
4	Demanding new challenges	1
	Total	69

The component that represents the most demanding new challenge according to this assessment is the electrical transfer unit; the unit that has to transfer the power generated by the RNA across the weathervaning pivot buoy to the subsea cable.

Other significant challenges identified are the connection between upper and lower body of the PivotBuoy and possible application of certain materials (e.g. Dyneema tether material).

Table 3: Technology assessment results for phases (activities)

Technology class	Class definition	Number of components
1	No new technical challenges	72
2	New technical uncertainties	18
3	New technical challenges	2
4	Demanding new challenges	0
	Total	83

The most technically challenging activities identified are the corrosion protection during fabrication of partially ballasted / wetted compartments and RNA access. Other challenging activities identified include; structural design (RNA dynamic loads), fabrication tolerances of yaw system, sea fastening during transport, installation of components (gravity base, tendons), hook-up and commissioning of the electrical power system and condition monitoring.

The technology assessment matrix is included in full in Appendix A. The results of the technology assessment can be seen as a first, high level identification of the major project hazards (HAZID). The identified hazards are used for a further assessment that also allows accounting for the consequences of failure of a certain system component. This is addressed in the next section, see Section 4.

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4 FMECA PROCESS

Purpose and method

To better prioritize the design development efforts, a method is required that not only categorize the technology complexity but that also considers the consequences of technology functioning for the system performance.

The objective of this step is to identify relevant failure modes with underlying failure mechanisms for the elements of the PivotBuoy in order to prioritize the detailed design efforts. The output of this step will be a list of possible failure modes for each of the main components of the PivotBuoy system and a quantification of the associated risks (risk being the combination of failure probability and consequence of failure). Subject matter experts will identify the possible failure modes and their judgement is applied to assign probability and consequence values to each identified failure mode.

A systematic approach for identification of possible failure modes and their related failure mechanisms is required. There are several threat or failure mode identification techniques available. Considering the early phase of system development, a suitable method to perform such an assessment is the Failure Mode, Effects and Criticality Analysis (FMECA) as described in DNV-RP-A203. An FMECA is considered systematic, and is simple to apply on a high level defined system.

The system is divided into main and sub-components generally following the division used for the technology assessment discussed in Section 3. However, the method is applied to the preliminary design as developed from the concept design during and after the performance of the technology assessment. The system changes during this development also resulted in the use of different terminology for similar components. Then (sub-)component failures (or hazards) are identified (a high level HAZID or HAZard IDentification) and the effect of the failure analyzed.

System components and sub-components

The main component breakdown applied for the FMECA has been:

- Foundation (Gravity base)
- Mooring (TLP anchoring)
- Pivot Bottom (PivotBuoy - lower body)
- Pivot Top (PivotBuoy - bearing system)
- Pivot Top (PivotBuoy - upper body)
- Pontoons & Masts (Truss structure)
- Main Columns (Buoyancy elements)
- Electrical power
- Utilities

Element definition and used terminology are reflecting the preliminary system design at the time of technology assessment execution (equivalent concept design component is given in brackets).

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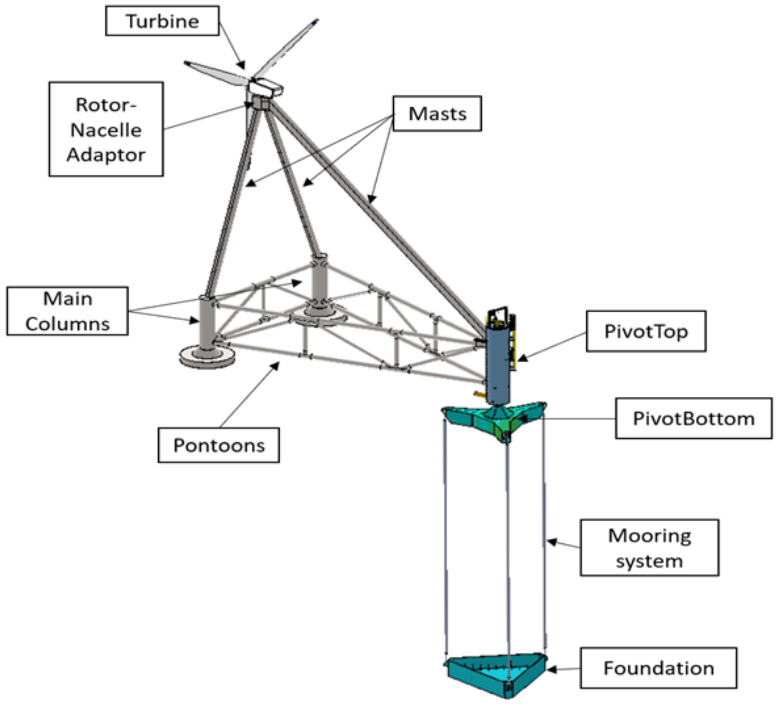
The nacelle / turbine is not included here as a component since it is not part of the project scope. This part of the structure will be purchased as fully functional (re-cycled) component and is not part of the scope of this risk identification process.

The main components are shown in Figure 3, where also the further division in sub-components is shown.



Main and sub- components

- Turbine
- Foundation
  - Main structure
  - Tether interfaces
  - Seabed interface
  - Scour protection
- Mooring
  - Upper tether joints
  - Tendons
  - Length adjustment section
  - Lower tether joints
- pivot bottom
  - main structure and tether interface
- pivot top
  - bearing and elastomeric mount
- pivot top
  - main structure and center shaft
  - room/deck house
  - upper deck and boat landing
- Pontoons & masts
  - wet and dry structure
  - nacelle mounting
  - walkways
- Main columns
  - Buoyancy elements
  - Heave damping skirts
- Electrical power
  - RNA to buoy
  - transfer unit
  - riser and cable
  - end location
- Utilities
  - control/ power/ nav/safety/scada

Figure 3. Identification of component and sub-components

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Risk categories

The risk category, as combination of probability and consequence, is assigned following the guidelines given in DNVGL-SE-0422

The probability class assignment is done based on the values given in Table 4.

Table 4: Probability classes

Class	Name	Description	Reference
1	Very low	Negligible event frequency	Accidental
2	Low	Event unlikely to occur	Strength / ULS
3	Medium	Event rarely expected to occur	Fatigue / FLS
4	High	One or several events expected to occur during the lifetime	Operation low frequency
5	Very high	One or several events expected to occur each year	Operation high frequency

The consequence classes are as defined in Table 5.

Table 5: Consequence classes (floating turbine or component)

Class	Description of consequences (impact on)				
	Safety	Environment	Operation	Assets	Cost (€)
1	Negligible injury or health effects	Negligible pollution or no effect on environment	Negligible effect on production (hours)	Negligible	1k
2	Minor injuries or health effects	Minor pollution / slight effect on environment (minimum disruption on marine life)	Partial loss of performance (retrieval not required outside maintenance interval)	Repairable within maintenance interval	10k
3	Moderate injuries or health effects	Limited levels of pollution, manageable / moderate effect on environment	Loss of performance requiring retrieval outside maintenance interval	Repairable outside maintenance interval	100k
4	Significant injuries	Moderate pollution, with some clean-up costs / Serious effect on environment	Total loss of production up to 1 m (€)	Significant but repairable outside maintenance interval	1m

The combination of probability and consequences results in a risk ranking as shown in Table 6.

Table 6: Consequence classes (floating turbine or component)

	Consequences				
Probability	1	2	3	4	5
5	Low	Med	High	High	High
4	Low	Med	Med	High	High
3	Low	Low	Med	Med	High
2	Low	Low	Low	Med	Med
1	Low	Low	Low	Low	Med

Low : Tolerable, no action required
Medium : Mitigation and improvement required to reduce risk to low
High : Not acceptable, mitigation and improvement required to reduce risk to ALARP

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Method application

In preparation for the plenary FMECA session, INTECSEA compiled a table with the components as defined during the technology assessment session and adjusted and extended these with suitable sub-components. For each sub-component, failure modes and effects were identified and described in the table. This populated table was issued to the consortium partners for review and preparation in advance of the general FMECA session.

This plenary meeting was held in the X1 Wind offices in Barcelona on the 17th and 18th of July 2019. The FMECA session was led by INTECSEA and was attended by the following other consortium members:

- X1 WIND
- WAVEC
- PLOCAN
- EDP CNET
- DNV GL
- DEGIMA

During this meeting, component and sub-component definition, failure modes and effects were reviewed and updated. The probability and consequence assignment were discussed and agreed as well. The results of the meeting were later used by INTECSEA to update and complete the FMECA sheet.

The minutes of these meetings are summarized in [Ref 2].

Expert judgement is applied to assign probability and consequence values to each identified failure mode. The subject experts present during this session were from all relevant fields of expertise including; design, fabrication, installation, certification, wind-power, offshore structures, etc.

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FMECA findings

The number and type of FMECA identified risks are summarized in Figure 4.

Number of occurences — total risks 278

Increase in consequence →; Increase in prob ↓

Conseq	1	2	3	4	5	total
Prob						
1	-	-	11	27	10	48
2	-	2	12	110	51	175
3	-	3	4	33	11	51
4	-	-	-	4	-	4
5	-	-	-	-	-	0
total	0	5	27	174	72	

Figure 4. Summary of FMECA findings

For the 278 failure modes as identified for the entire structure, a risk value (low=green, medium=yellow, high=red) has been determined. Of this total of 278 risks, 15 are in the category high, 208 are category medium and 55 are category low.

The actions that result from the FMECA process are summarized in Table 7. The general recommended actions that are applicable for a sub-component are typically also applicable for the entire component and for the entire structure. This results in a list of generally applicable actions that are seen as a means to reduce most of the identified risks. These can be seen as the most significant recommended preventive actions, and they are summarized at the top of the table.

In addition, there are actions identified to reduce risks related to specific sub-component's failure mode. These failure-mode-specific recommended actions are listed in the lower part of the table. Those actions that are related to a high risk sub-component / failure mode are listed above the ones related to medium risk sub-components. Note that sub-components with risk rating 'low' do not require mitigative action (risk is tolerable) according to the code (DNVGL-SE-0422). Nevertheless, for many sub-components with low risk, preventive actions to further reduce the risk are given in the full record as included in Appendix B.

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Table 7: Identified actions from FMECA

Applicable to the (sub-)component;	Preventive action	Risk [1)]
All (sub-) components	**General preventive actions[3)]**	
	Collection of design data for load definition	Low / Med / High
	Perform engineering and design	
	Engineering and design QA / QC	
	Material selection, specification and QC	
	Perform installation engineering	
	Prepare installation procedures	
	Prepare operating procedures	
	Monitoring and inspection	
	Specific preventive actions	
Upper tether joints of TLP anchoring	Reduce stress level through over-dimensioning Onshore integration testing / add locking mechanism	High
Tendons	Model dynamic behaviour	High
Main structure buoy lower body	Early detailed logistics planning / transportation procedure	High
Buoy lower body tether interface and nacelle mounting	Overdimensioning of components / Minimize SCFs (e.g. weld dressing)	High
Truss structure (dry)	Analyze sensitivity cases	High
Elastomeric mount Truss structure (dry) Electrical transfer unit Riser power cable	General preventive actions as shown above apply	High
Note [2)]	Add conservatism, redundancy, over-dimensioning	Medium
Note [2)]	Definition of seismicity risk and loads	Medium
Note [2)]	Structure dynamic behaviour modelling, model calibration, sensitivity cases	Medium
Tether joints	Mitigate sand ingress potential, maintain elevation above seafloor, consider (local) sheathing	Medium
Tether joints	Specify galvanized wires	Medium
Tether joints	Tight dimensioning and self aligning design	Medium
Note [2)]	HVAC design	Medium
Note [2)]	Structure and anchoring lay-out design	Medium
Power cable	Design and install bend restrictors	Medium
Note [2)]	Fabrication and installation QC	Medium
Note [2)]	Trial fit onshore before installation	Medium
Note [2)]	Transportation procedure, protective measures during transport and handling	Medium
Note [2)]	Installation contractor selection, equipment selection, reliable weather prediction for installation	Medium
Ballast gravity base	Confirmation of components weight	Medium
Length adjustment section tendons	Apply markings to allow visual inspection	Medium
Note [2)]	Survey data QC, sediment transport prediction, assessment nearby structures, soil model and structure interaction, survey during operation	Medium
Power, SCADA	Specialist input; SCADA, commissioning	Medium
Note [2)]	Maintenance and inspection program and procedures	Medium
Buoyancy elements and cable on seabed	Early contact and information of fishermen and other 3rd parties	Medium

Notes;
1) The number of "High" and "Medium" cases in this table does not match the number shown in Figure 4, more than one (sub-)component / failure mode can result in the same specific preventive action or is covered by the general preventive actions
2) These preventive actions apply for more sub-components than can be listed here, refer to the full FMECA sheet attached in the Appendix for details
3) Where general preventive actions mention design, QA/QC, preparation of procedures, this refers to preparation of a set of documents that is common for the activity and in line with requirements of a relevant standard (ISO / DNVGL / etc.). For example for QC this involves preparation of a testing and inspection plan, collection of test records and certificates, etc. to come to a set of documents as would be required for DNVGL classification.

The FMECA register is included in full in Appendix B.

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5 HEALTH, SAFETY & ENVIRONMENT

General

Both health & safety (H&S) and environmental aspects have been considered when performing the technology assessment and the FMECA. Specific examples of H&S and environmental aspects relevant to this PivotBuoy project are presented below.

In general, it is a principal objective of the project to ensure that the design of the PivotBuoy facilities complies with applicable safety, health, working environment and environmental requirements. This applies during all phases of the project execution: from design through to installation and offshore operations. In addition the ALARP principle will apply, meaning the risk will be reduced to "as low as reasonably practicable". Task 6.2 will continue to assess and monitor health and safety risks by reviewing design, specifications and procedures, and initiating additional risk reduction activities when necessary, which will be included in the Deliverable update D6.2 Update of reliability, Health & Safety and Environmental Assessment due in month 15.

Ensuring a compliant design is achieved through implementation of the following design considerations:

- Identifying risks early in the design process so that they can be managed. This is being done on PivotBuoy through the preliminary risk assessment activities described in this report.
- Apply 'Inherently Safe' design principles. This means that, where practicable, decisions are taken to 'design away' the identified risks. Passive solutions that reduce the probability component of a risk are preferred over active solutions that mitigate the consequence component of a risk. In other words, it is better to prevent an undesirable event altogether than to try to manage the consequences of such event once it has occurred.
- Minimizing the potential environmental impact during all phases of the project by considering environmental aspects.
- Maximizing the benefits of protection measures; both environmental and safety-related. This means selecting protection measures that are cost-effective, robust and practical to implement.

Health & Safety Aspects

Reference is made to Appendices A and B for the complete risk assessment registers.

The following key health and safety aspects were identified in the course of the risk assessment activities performed to date:

- Personnel transfer to/from the floating facility, including the ability to evacuate injured personnel from the facility, should be considered for the boat landing
- Personnel access to the nacelle, potentially via the main mast, requires consideration of physical access limitations and working environment aspects (e.g. enclosed spaces, slip hazards, etc)
- Personnel access and working environment within the control room areas

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- Personnel movements on the facility; i.e. walkways and stairs
- Material handling on the facility both during installation and operation (maintenance)
- Potential for unauthorized access to the floating unit
- Potential for collision by other users of the sea (3^{rd}-party vessels)
- General installation / removal risks relating to marine vessel operations, towing and lifting activities
- Specific installation / removal risks relating to manned underwater operations (diving)

Environmental Aspects

Risks to the environment have been considered during the initial risk assessment activities; however, the technology assessment and FMECA processes (being based on review at the component level), do not always identify all relevant environmental risks. A separate desk-top exercise has therefore been conducted with the specific objective to identify environmental risks during the three main phases of the project offshore; namely, installation phase, operating phase and removal phase.

The identified risks for each of these phases are listed below. These risks will be considered during the ongoing design process.

Environmental Impact Risks during Installation Phase:

- Potential for spills (e.g. fuels or hydraulic fluid) from marine vessels or installation equipment
- Above-water noise emissions from marine vessels exceeding established limits
- Below-water noise emissions from marine vessels, including the installation of the mooring system (anchor, cables, etc.), exceeding established limits
- CO_2 and NOx emissions from marine vessels and installation equipment exceeding established limits
- Disturbance of the seabed sediments and benthic species (for example during placement of structures or cables) beyond approved limits

Environmental Impact Risks during Operation Phase:

- Potential for spills (e.g. bearing lubricant) from PivotBuoy system
- Potential for spills from operational support vessel
- Above-water noise emissions from turbine exceeding established limits
- Below-water noise emissions (vibrations) from turbine and mooring system exceeding established limits
- Above-water noise emissions from operational support vessel exceeding established limits
- Below-water noise emissions (vibrations) from operational support vessel exceeding established limits
- CO_2 and NOx emissions from operational support vessel exceeding established limits
- Harm to aquatic fauna (fish, cetaceans, etc)
- Harm to bird life
- Interaction with other users of the marine space (fishing, shipping, etc.)

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Environmental Impact Risks during Removal Phase:

- Potential for spills (e.g. fuels or hydraulic fluid) from marine vessels or equipment
- Above-water noise emissions from marine vessels exceeding established limits
- Below-water noise emissions from marine vessels, including the installation of the mooring system (anchor, cables, etc.), exceeding established limits
- CO_2 and NOx emissions from marine vessels and equipment exceeding established limits
- Disturbance of the seabed sediments and benthic species (for example during removal of structures or cables) beyond approved limits

Furthermore, environmental assessments will be performed as part of project Task 6.3, lead by PLOCAN, and where applicable the findings will be included in deliverables D6.2 and D6.3 as updates of subject report.

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6 CONCLUSIONS AND WAY FORWARD

This report presents the initial hazard identification and potential failure modes, reliability and health and safety and environmental assessment of the PivotBuoy system. It is intended to identify the challenges and uncertainties that need to be addressed in subsequent steps of the system development. The technology assessment is based on the conceptual design at the start of the project, while the FMECA is based on the preliminary design system as it has developed up to the moment of issue of subject report.

The findings of this assessment have resulted in a list of considerations and recommendations to 'design out' the potential risks, including health, safety and environmental risks, during all phases of the project: design, fabrication, installation, operation and decommissioning.

During further development of the PivotBuoy system, the recommended actions that follow from this initial risk assessment shall be considered. On completion of detailed design a new risk assessment will be performed to identify the remaining risks. That future assessment will be based on the full set of drawings, specifications and procedures that will be available at the time.

In conclusion, it can be stated that this initial risk assessment (technology assessment and FMECA) has identified the focus areas for the next development phase of the PivotBuoy project in order to minimize project risk. None of the identified risks suggests that the PivotBuoy project cannot be completed as planned or requires resolution before the next phase of the project (detailed design) can start.

The updated results of the assessment will be included in deliverable *D6.2 - Update of reliability, Health & Safety and Environmental Assessment* due in month 15 and *D6.3 - Final Reliability, Health & Safety and Environmental Assessment of PivotBuoy system* due at the end of the project (month 33).

7 REFERENCES

[Ref 1] MOM_19012, Minutes of Meeting - Kick-off Meeting, 15-16 May 2019, Brussels, Belgium.

[Ref 2] MOM_19013, Minutes of Meeting - Preliminary Design Review, 17-18 July 2019, Barcelona, Spain.

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APPENDIXES

APPENDIX A – Technology Assessment Register

APPENDIX B – FMECA Register

These Appendixes have not been made publicly available due to IPR reasons.

In case third parties would like to request access to more detailed information, please get in contact with the project coordinator or through the project website:

Project Website: http://pivotbuoy.eu/contacts/

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