D7.2 Final Report

ShallowFloat

Prepared for:

National Offshore Wind Research and Development Consortium

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Acronyms and Abbreviations

ABS	American Bureau of Shipping
AEP	Annual Energy Production
CAPEX	Capital Expenditure
DLC	Design Load Case
FOWT	Floating Offshore Wind Turbine
IAB	Internal Advisory Board
LCOE	Levelized Cost of Energy

Executive Summary

The purpose of this report is to document the execution and results of the ShallowFloat project. This project is focused on the design, modeling and development of innovative mooring systems for semi-submersible platforms in a shallow water, commercial-size wind farm. In Floating Offshore Wind, to-date, most floating offshore wind turbines FOWTs have been deployed in relatively shallow (<200m) water.

The NOWRDC/NYSERDA-funded ShallowFloat project is aimed at reducing the cost of the mooring system for the WindFloat when deployed in transitional water depths (40-70m). The use of traditional catenary mooring systems in transitional water depths for semisubmersible platforms can lead to large 'snap' loads on the mooring system, driving up maximum loads and system cost.

A site was selected and site-specific baseline mooring designs developed, followed by detailed design of a site-specific mooring design incorporating the SeaSpring product under development by Technology from Ideas. Open-source design tools were updated for inline mooring spring applications. An American Bureau of Shipping Approval-in-Principle was achieved.

The ShallowFloat consortium thanks NOWRDC/NYSERDA for enabling this project through its financial support and guidance. Thanks also goes to our subawardees and vendors without whom this project would not have been possible: TFI for providing the spring technology and guidance on designing mooring systems with springs, NREL for their contributions to open-source designs and collaboration, Aker Solutions for coordination and execution of testing, and ABS for serving as an independent reviewer in order to achieve Approval in Principle.

1 Objectives and Accomplishments

This award allowed Principle Power and the project consortium to demonstrate a number of key objectives. A number of tasks and milestones were laid out at the beginning of the project. The actual performance against the stated milestones is summarized here.

Table 1. Milestones and Deliverables

Tasks and Milestones	Deliverables
Task 0: Project Management M0.2 Complete a brief report regarding the project kickoff meeting and minutes, including detailed project plan, Gantt chart M0.3 Complete a list of members of the Advisory Group; summaries of Advisory Group discussions. M0.5.1 Complete Annual Metrics Report #1 M0.5.2 Complete Annual Metrics Report #2 MX.Y Quarterly Reports	D0.2: A brief report regarding the project kickoff meeting and minutes, including detailed project plan, gantt chart. **Actual Performance:** (23-Sep-21) [100%] D0.3 A list of members of the Advisory Group; summaries of Advisory Group discussions. **Actual Performance:** (29-Sep-21) [100%] D0.4: A brief report regarding the project completion meeting and minutes. **Actual Performance:** () [100%] D0.5.1 Annual Metrics Report #1 **Actual Performance:** (31-Jan-22) [100%] D0.5.2 Annual Metrics Report #2 **Actual Performance:** (13-Mar-23) [100%] *DX.Y Quarterly reports were also included in this work package. Full list of quarterly reports not included for simplicity.
Task 1: Project Documentation, Representative Site Selection and Environmental Conditions M1.1 Prepayment #1 to NREL M1.2 Complete Site selection report M1.3 Complete Design Basis based on the procured metocean data for sites selected in Milestone 1.1, with a particular focus to obtain more detailed data for one such promising site.	D1.1 Prepayment #1 to National Lab to cover work performed in Task 1 and Task 2 **Actual Performance:** (15-Jul-21) [100%] D1.2 Site selection report **Actual Performance:** (04-Oct-21) [100%] D1.3 Design basis **Actual Performance:** (09-Feb-22) [100%]

Task 2: Mooring Component Development M2.1 Complete techno-economic feasibility study on polymer spring technology	D2.1 Techno-economic feasibility study on polymer spring technology **Actual Performance:** (31-Jan-22) [100%]
Task 3: Open-Source Software Development M3.1. Beta release of updated features of MoorDyn, with verification results. M3.2 Prepayment #2 to National Lab M3.3 Complete a mooring report detailing effect of non-linear spring on response of open-source hull and mooring system	D3.1. Beta release of updated features of MoorDyn, with verification results. **Actual Performance:** (15-Jun-22) [100%] D3.2. Prepayment #2 to National Lab to cover work performed in Task 3 **Actual Performance:** (11-May-22) [100%] D3.3 Mooring report detailing effect of non-linear spring on response of open-source hull and mooring system **Actual Performance:** (30-Jan-23) [100%]
Task 4: Mooring Design M4.1 Complete preliminary mooring report and load analyses of WindFloat mooring systems, considering possible configurations for shallow water mooring systems. M4.2 Complete final Mooring report and load analyses of WindFloat mooring systems, detailing optimal mooring design for WindFloats for each case study site and indicative inter-array cable layout M4.3 Receive an Approval-In-Principle (AIP) of WindFloat mooring system at PPI selected site	D4.1 Preliminary mooring report and load analyses of WindFloat mooring systems **Actual Performance:** (15-Jan-23) [100%] D4.2 Final mooring report and load analyses of WindFloat mooring systems **Actual Performance:** (21-Jun-23) [100%] D4.3 AIP of WindFloat mooring system **Actual Performance:** (9-July-24) [100%]
Task 5: Farm Layout and Cabling Optimization M5.1 Prepayment #3 to National Lab M5.2 Compete technical note on the scaling of the polymer spring, behavior and its consequences for full scale prototypes M5.3 Proof that Polymer spring test specimen delivered to Aker test facility M5.4 Complete technical report on response of polymer spring based on completion of quasi-static and	D5.1 Prepayment #3 to National Lab to cover work performed in Task 5 and 6 **Actual Performance:** (12-Oct-22) [100%] D5.2 Technical note on the scaling of the polymer spring **Actual Performance:** (02-Jun-23) [100%] D5.3 Polymer spring test specimen delivered to Aker test facility **Actual Performance:** (17-May-23) [100%] D5.4 Technical report on response of polymer spring **Actual Performance:** (09-Apr-24) [100%]

dynamic testing of polymer spring and validation of response curve for test specimen polymer spring technology	
Task 6: Innovation Impact, LCOE Reduction, and Dissemination M6.1 Complete report on commercial cost estimation for large-scale polymer springs M6.2 Complete detailed LCOE report on shallow-water mooring systems with commercialized cost targets based on inter-array cable design for a bankable shallow-water mooring system	D6.1 Report on commercial cost estimation for large-scale polymer springs **Actual Performance:** (27-Jun-24) [100%] D6.2 Detailed LCOE report on shallow-water mooring systems with commercialized cost targets based on inter-array cable design for a bankable shallow-water mooring system **Actual Performance:** (29-July-24) [100%]

2 Project Activities

In Task 1, the study site was selected from several potential candidates, based on a combination of AEP potential, commercial region interest, and bathymetry. The site was located in the NY Bite, with a water depth of 50m. Its baseline metocean and seabed conditions were characterized for use in early-stage design assessments. A metocean data and analysis was obtained from a reputable commercial service provider. From these sources, environmental loads and mooring Design Load Cases (DLCs) were determined, in accordance with the relevant industry standards. These design documents were also reviewed and approved by ABS for use in the mooring and analyses being submitted for Approval-in-Principle (AIP).

In Task 2, based on the DLCs determined in Task 1, an early assessment of likely mooring load ranges was carried out to provide design envelopes for SeaSprings and a techno-economic feasibility assessment were conducted. Additionally, TFI provided guidance and inputs required for a mooring system designer to perform mooring design and analysis for a system that incorporated the SeaSpring component.

In Task 3, there was a large effort by the project team at National Renewable Energy Laboratory (NREL) to improve OpenFAST, one of the primary open-source fixed and floating wind design and analysis tools. These improvements included expanded capabilities to include mooring springs in the mooring design. All improvements were verified against existing commercial software OrcaFlex. NREL then used this updated capability in OpenFAST to develop three mooring system designs: a baseline catenary, catenary with SeaSpring, and a taut system with SeaSprings. All three designs considered an open-source platform hosting a 15MW wind turbine.

In Task 4, baseline mooring and spring mooring systems for a single FOWT were developed for the WindFloat™ platform by Principle Power. Additionally, a taut mooring design considering SeaSprings was developed. These mooring systems were used to evaluate the impact of the incorporation of springs on mooring design, feasibility, and performance.

Towards the end of this work, the catenary mooring system design including the TFI SeaSpring was submitted to ABS to receive Approval-in-Principle. This was successfully granted, which further improves the techno-economic feasibility of springs in commercial scale applications, since it acknowledges an independent risk identification and review by a Classification Society.

In Task 5, large scale bench testing of the SeaSpring component was performed. The objectives of the test were to verify the quasi-static and dynamic response of the SeaSpring component, and to perform durability testing to measure its fatigue performance due to low cycle count, large magnitude, load cycles. The response testing showed good agreement between TFI's predicted response and the observed response, increasing confidence in the numerical modeling of SeaSpring components. Durability testing was performed until failure of a polymer weld was observed. Data from the failure and failure mode have been used by TFI to improve manufacturing processes to yield improved durability in future components. Outside of ShallowFloat, TFI is looking to validate these manufacturing process improvements with another large component test.

Based on the work done in these Tasks, an economic assessment of single and shared anchors was carried out by NREL on the mooring systems for WindFloat® and open-source submersibles respectively. This economic assessment showed for the open source design, the catenary system with SeaSprings increased LCOE by 1% over the baseline catenary system. The Taut mooring design including SeaSprings yielded a reduction in LCOE of 1.7% compared to the baseline catenary system. For the Principle Power mooring system, the catenary system with SeaSprings yielded a 0.4% decrease in LCOE compared to the baseline catenary system, while the taut system yielded a 1.9% decrease in LCOE. Differences between PPI and NREL results arise from a few factors, including different mooring system designs, and different assumptions on the impact on mooring installation costs between designs. It is important to also note that all mooring designs utilizing SeaSprings resulted in a reduction on required chain diameter size compared to the baseline catenary system. Large diameter chain can be difficult to procure in large quantities, so even in cases with less cost impact, the SeaSprings may allow an accelerated timeline or unlock the feasibility of a mooring design due to supply chain constraints.

There have been several benefits generated by this project:

1. Technical derisking and Approval in Principle of a spring mooring system in a commercially-considered region.
2. Preparation of the Principle Power mooring teams and our project partners to create a workflow for investigating the usage of mooring springs in future commercial projects.
3. Improving the capabilities of standard open-source analytical tools (OpenFAST & FAST.Farm).
4. Increasing the existing body of knowledge around the design, and use of springs in mooring systems.
5. Strong collaborative relationships developed among commercial partners, and research laboratories.

Several areas for follow-on work have been identified, including but not limited to:

1. Further identification & optimization of key mooring design parameters for spring mooring systems to better trade off the SeaSpring costs vs. other mooring component costs.
2. TFI is working to refine manufacturing processes to reduce defects, with plans to perform another full scale component bench test to verify that the improved manufacturing methods yield the expected improvement in durability.

The project has helped further TFI's pathway to commercialization of the SeaSpring technology. The large scale component test has been used to test manufacturing scalability to larger scale components than previously tested. For Principle Power's usage, the project will help inform potential usage of the SeaSpring technology on projects, and identify any future areas of technical risk that require mitigation prior to implementation.

3 Project Outputs

A. Journal Articles

none

B. Papers

“Design and Analysis of a Floating-Wind Shallow-Water Mooring System Featuring Polymer Springs” (Seojin Kim, Bradley Ling, Paul McEvoy) Proceedings of the ASME 2022 4th International Offshore Wind Technical Conference 2022-98149

“Turbulent wind simulation duration’s impact on mooring fatigue damage for Floating Offshore Wind Turbines” (Alistair Lee, Bradley A. Ling, Bruce Martin). Proceedings of the ASME 2023 5th International Offshore Wind Technical Conference 2023-119345[1]

C. Status Reports

A series of quarterly reports were generated and submitted for the project.

D. Media Reports

E. Invention Disclosures

none

F. Patent Applications/Issued Patents

None

G. Licensed Technologies

none

H. Networks/Collaborations Fostered

Furthered PPI collaboration with NREL on developing open-source mooring tools.

I. Websites Featuring Project Work Results

None

[1] Jointly supported by NOWRDC Agreement #145018 (Deep-Water Mooring Systems for Floating Wind Farms)

J. Other Products (e.g. Databases, Physical Collections, Audio/Video, Software, Models, Educational Aids or Curricula, Equipment or Instruments)

none

K. Awards, Prizes, and Recognition

None