Demonstration of NREL Modeling Capability to Design the Next Generation of Floating Offshore Wind Turbines with Stiesdal and Magellan Wind

Cooperative Research and Development Final Report

CRADA Number: CRD-19-00787

NREL Technical Contact: Jason Jonkman

NREL is a national laboratory of the U.S. Department of Energy
Office of Energy Efficiency & Renewable Energy
Operated by the Alliance for Sustainable Energy, LLC

This report is available at no cost from the National Renewable Energy Laboratory (NREL) at www.nrel.gov/publications.

Contract No. DE-AC36-08GO28308

Technical Report
NREL/TP-5000-82246
February 2022

Demonstration of NREL Modeling Capability to Design the Next Generation of Floating Offshore Wind Turbines with Stiesdal and Magellan Wind

Cooperative Research and Development Final Report

CRADA Number: CRD-19-00787

NREL Technical Contact: Jason Jonkman

Suggested Citation
Jonkman, Jason. 2022. *Demonstration of NREL Modeling Capability to Design the Next Generation of Floating Offshore Wind Turbines with Stiesdal and Magellan Wind: Cooperative Research and Development Final Report, CRADA Number CRD-19-00787.* Golden, CO: National Renewable Energy Laboratory. NREL/TP-5000-82246. https://www.nrel.gov/docs/fy22osti/82246.pdf.

NREL is a national laboratory of the U.S. Department of Energy
Office of Energy Efficiency & Renewable Energy
Operated by the Alliance for Sustainable Energy, LLC

This report is available at no cost from the National Renewable Energy Laboratory (NREL) at www.nrel.gov/publications.

Contract No. DE-AC36-08GO28308

Technical Report
NREL/TP-5000-82246
February 2022

National Renewable Energy Laboratory
15013 Denver West Parkway
Golden, CO 80401
303-275-3000 • www.nrel.gov

Cover Photos by Dennis Schroeder: (clockwise, left to right) NREL 51934, NREL 45897, NREL 42160, NREL 45891, NREL 48097, NREL 46526.

NREL prints on paper that contains recycled content.

Cooperative Research and Development Final Report

Report Date: February 19, 2022

In accordance with requirements set forth in the terms of the CRADA agreement, this document is the CRADA final report, including a list of subject inventions, to be forwarded to the DOE Office of Scientific and Technical Information as part of the commitment to the public to demonstrate results of federally funded research.

Parties to the Agreement: Stiesdal Offshore Technology (Stiesdal A/S); Magellan Wind LLC

CRADA Number: CRD-19-00787

RADA Title: Demonstration of NREL Modeling Capability to Design the Next Generation of Floating Offshore Wind Turbines with Stiesdal and Magellan Wind

Responsible Technical Contact at Alliance/National Renewable Energy Laboratory (NREL):

Jason Jonkman | jason.jonkman@nrel.gov

Name and Email Address of POC at Company:

Henrik Stiesdal | nst@stiesdal.com

Jeffrey Kehne | jkehne@magellanwind.com

Jim Lanard | jlanard@magellanwind.com

Sponsoring DOE Program Office(s): Office of Energy Efficiency and Renewable Energy (EERE), Wind Energy Technologies Office

Joint Work Statement Funding Table showing DOE commitment:

Estimated Costs	**NREL Shared Resources a/k/a Government In-Kind**
Year 1	$250,000.00
Year 2	$250,000.00
TOTALS	$500,000.00

Executive Summary of CRADA Work:

This Technology Commercialization Fund (TCF) CRADA involved demonstration of NREL modeling capability using OpenFAST (formerly known as FAST) to design the next generation of floating offshore wind turbines (FOWT) with Stiesdal's TetraSpar design. The objective of the project was to enable the design and optimization of next generation FOWT that show promise to make FOWT cost-competitive with other energy technologies by upgrading, verifying, and validating improvements to OpenFAST. This objective was achieved by (1) upgrading OpenFAST to compute floating substructure flexibility and member-level loads, which is critical to enable the design of floating substructures—especially newer designs that are streamlined, flexible, and cost-effective; (2) verifying the new OpenFAST capabilities through model-to-model comparisons and validating the capabilities through comparisons to empirical data generated with wave-tank testing, using TetraSpar data provided by Stiesdal; and (3) making available the upgraded OpenFAST tool to the wind energy community to enable next-generation floating wind designs.

Summary of Research Results:

OpenFAST has a long history of supporting the design of the pre-commercial floating wind prototypes worldwide. However, the substructure for a floating wind turbine has historically been modelled in OpenFAST as a rigid body with hydrodynamic loads lumped at a point, which enabled the tool to predict the global response of the floating substructure but not the structural loads within its individual members. This limitation is an impediment to designing floating substructures—especially newer designs that are more streamlined, flexible, and cost-effective. It is envisioned that the new capability in OpenFAST developed and verified in this project will enable the design and optimization of advanced floating wind technologies. This implementation is part of a larger effort in the U.S. Department of Energy (DOE) Wind Energy Technology Office (WETO) and DOE Advanced Research Projects Agency-Energy (ARPA-E) Aerodynamic Turbines Lighter and Afloat with Nautical Technologies and Integrated Servo-control (ATLANTIS) programs to develop an open-source, multifidelity systems-analysis capability for FOWT analysis and optimization that captures the relevant physics and costs that drive designs and trade-offs.

Regardless of a few setbacks, this project significantly advanced the state of the art in modeling of floating offshore structures for wind and is considered a major success. With the public release of the OpenFAST upgrade fulfilled, the key project output—the release of the upgraded OpenFAST software to enable the advancement of the floating offshore wind industry—was achieved. The upgraded OpenFAST tool will enable the floating offshore wind industry to design and analyze more streamlined and flexible substructures, allowing designers to push the boundaries of innovation.

This project generated one conference paper, three conference presentations, one technical report, an OpenFAST documentation upgrade, and one software release as follows:

- IOWTC 2019 paper and presentation titled, "Substructure Flexibility and Member-Level Load Capabilities for Floating Offshore Wind Turbines in OpenFAST" [1]
- DeepWind 2020 presentation and corresponding NREL technical report titled, "Implementation of Substructure Flexibility and Member-Level Load Capabilities for Floating Offshore Wind Turbines in OpenFAST" [2]
- Update to the online OpenFAST documentation for SubDyn titled, "SubDyn User's Guide and Theory Manual" (https://openfast.readthedocs.io/en/main/source/user/subdyn/index.html)
- WESC 2021 presentation titled, "Verification of Substructure Flexibility and Member-Level Load Capabilities in OpenFAST Against OrcaFlex for the TetraSpar Floating Offshore Wind Turbine Prototype"
- Public release of OpenFAST to the floating wind energy community via a pull request into the OpenFAST GitHub repository (https://github.com/OpenFAST/openfast/pull/537); merged into main branch released in OpenFAST v2.6.0 (https://github.com/OpenFAST/openfast/releases).

Overall, NREL completed much of the work planned within the CRADA. The major changes in project scope included:

- The OpenFAST model development was expanded in scope due to unanticipated modeling needs of the TetraSpar, e.g., the need to model revolute joints at the corners of the substructure that NREL was unaware of when the CRADA was established
- The full-scale properties of the TetraSpar prototype were used for verification of the upgraded OpenFAST tool against OrcaFlex, but validation against measured data from full-scale open-ocean testing of the TetraSpar prototype was not possible because the full-scale TetraSpar prototype was not fully operational by the project completion
- Progress was made on the validation of the upgraded OpenFAST tool against wave-tank test data, but the validation has not yet been completed. The intent of the originally proposed validation work will be completed in follow-on projects such as the IEA Wind Task 30 OC6 Phase IV and the ARPA-E ATLANTIS programs
- The proposed loads analysis of the TetraSpar to advance its technology readiness level was dropped.

The main reasons for rescoping are commensurate with the challenges faced throughout the project, including:

- The upgrades to OpenFAST took more effort than originally planned, because:
    - The work scope was expanded due to unanticipated modeling needs of the TetraSpar (see above)
    - The hydrodynamic improvements to OpenFAST took more effort than planned.
- The verification and validation took more effort than originally planned, because:
    - Issues associated with the new OpenFAST functionality (bugs in the source code, not revealed in the regression testing) were discovered and had to be fixed
    - Issues associated with hydro-elastic coupling and numerical stability, not revealed in the regression testing, were discovered and had to be fixed
    - Issues were found in the full-scale TetraSpar properties provided by Stiesdal (e.g., weight, buoyancy, and mooring pretension not balancing), which had to resolved
    - Issues were found in the TetraSpar properties provided by the University of Maine, e.g., many typos in the reports), which had to be resolved.

The project had five tasks, whose results are summarized next.

Task 1: Manage the Project

This task was used to establish the CRADA, track and report on the progress of the project, track financials, and to host meetings to discuss the project and next steps. Three physical face-to-face meetings were held between NREL and Stiesdal Offshore Technology, including the kick-off meeting at NREL, a wave-tank test at the University of Maine, and a mid-project review meeting associated with the IOWTC 2019 conference, where the project approach and results were discussed. A large number of online meetings were also held between NREL, Stiesdal, and Aalborg University during the code-to-code verification work of Task 4.

Task 2: Upgrade OpenFAST to Include Substructure Flexibility

Functional requirements were first established for modeling floating substructure flexibility and member-level loads in consultation with Stiesdal Offshore Technology and others in the floating wind industry, which were published and presented at IOWTC 2019 [1]. The functional requirements apply not just to the Stiesdal TetraSpar, but to a wide range of floating substructure concepts, including common configurations such as semisubmersibles, spars, TLPs, and hybrids, but also a much wider range of transformational substructures. For each functional requirement, the associated modeling approach was outlined, considering only approaches that maintain computational efficiency. The physics-based modeling needs identified included (see [1] for details):

- Substructure flexibility
- Member-level loads
- Pretensioned cables
- Rigid links
- Pin, universal, and ball joints
- Member-level hydrostatics
- Multiple large-volume bodies
- Both time domain and linearization analyses.

Functional requirements that were discussed, but outside the scope of the present project, are listed next. These will have to be addressed in future projects:

- Buoyancy cans
- Station-keeping systems with turret connections
- Hydro-elastics of large-volume floaters
- Structural nonlinearities in the substructure
- Transient dynamics of the installation procedure
- Transient dynamics of an active-ballast system
- Aerodynamic loads on multi-member support structures
- Slanted towers
- Multi-rotor concepts
- Local hydrodynamic pressure on large-volume bodies.

Next, detailed implementation plans and theory bases for modeling floating substructure flexibility and member-level loads in OpenFAST were developed, based on the functional requirements, which were presented at DeepWind 2020, documented in an NREL technical report [2] and the online SubDyn documentation (https://openfast.readthedocs.io/en/main/source/user/subdyn/index.html). Upgrades were made to the OpenFAST modules SubDyn (for substructural dynamics) and HydroDyn (for hydrodynamics), and the OpenFAST glue code (for coupling the updated SubDyn and HydroDyn modules to other OpenFAST modules). The new functionality supports hydro-elastic effects, together with coupling to the wind turbine and mooring system dynamics, for both nonlinear time-domain simulations and full-system linearization about an operating point.

Structurally, the new functionality includes the ability to model the substructure using a linear finite-element approach together with a Craig-Bampton reduction and static improvement method to improve computational efficiency. In addition to beam elements and cantilevered interconnections, pretensioned cable elements, rigid-link elements, and pin, universal, and ball joint interconnections have been introduced. The structural formation also now supports a floating reference frame, whereby the Guyan modes capture the rigid-body motion and the Craig-Bampton and static modes capture the structural elasticity, and moments are captured from applied forces and gravity in the deflected state.

Hydrodynamically, the new functionality supports member-level hydrostatics in the strip-theory solution (dependent on substructure displacement) and multiple potential-flow bodies (including optional interaction between these bodies). The strip-theory solution is applicable to slender members and the potential-flow-theory solution is applicable to large volume members, and both include first- plus second-order terms.

This new functionality is illustrated in Figure 1.

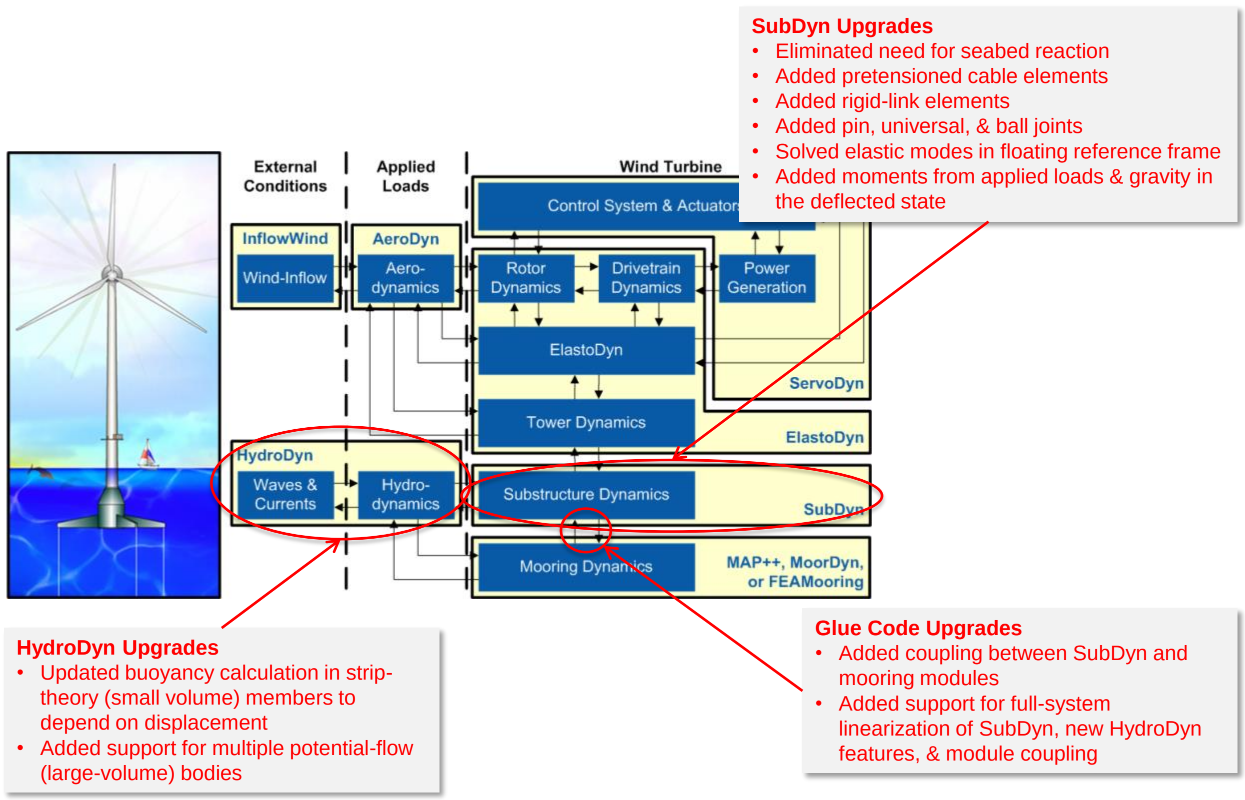

Figure 1: Overview of Upgrades to OpenFAST

The new functionality was then implemented in the OpenFAST source code, based on the detailed implementation plans. A series of regression tests were implemented to verify the proper implementation of the new functionality. Exemplary tests are illustrated in Figure 2 and included, e.g., a test of the new pretension cable element in SubDyn, a test of a pendulum in SubDyn with the new rotational joints, and a test of the new hydrostatic implementation dependent on displacement in the strip-theory solution. The updated source code was submitted to the OpenFAST GitHub repository via a pull request (https://github.com/OpenFAST/openfast/pull/537).

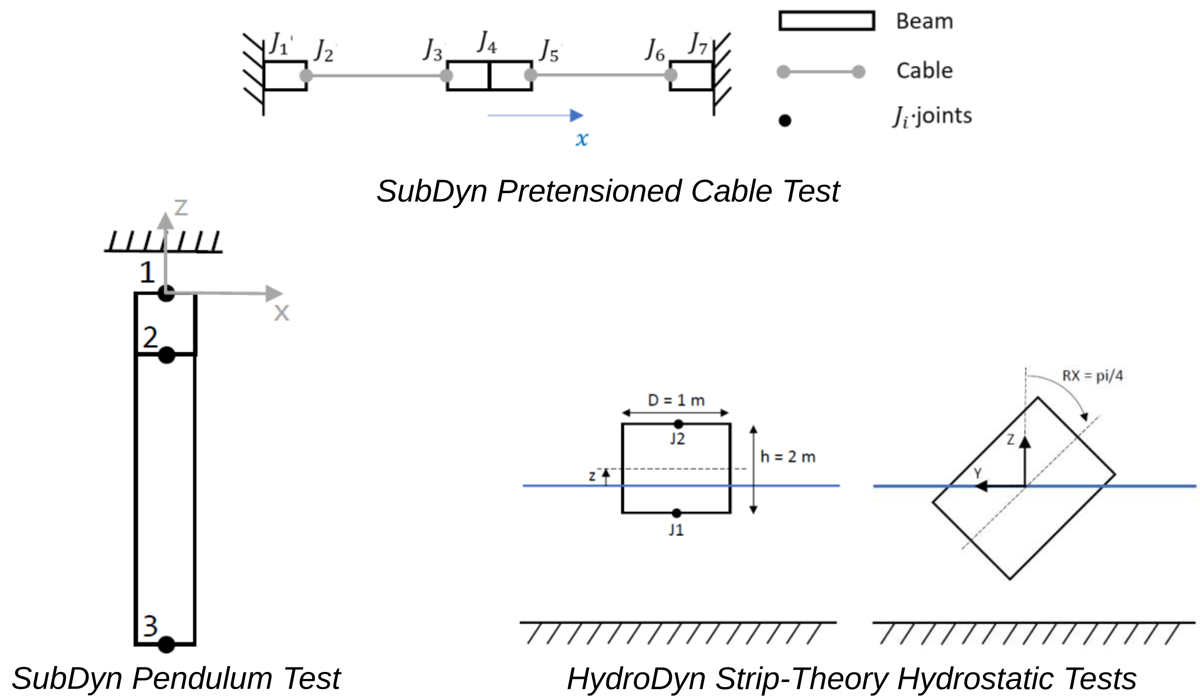

Figure 2: Illustration of New Module-Level Regression Tests

Once the full-system verification of the new OpenFAST functionality was completed (Task 4), the upgraded version of OpenFAST was migrated into the dev and then main branches of OpenFAST and publicly released in OpenFAST v2.6.0 to the floating wind energy community (https://github.com/OpenFAST/openfast/releases).

Task 3: Collect Data From the Full-Scale Prototype Test of the TetraSpar

It was not possible to collect measured data from full-scale open-ocean testing of the TetraSpar prototype because the full-scale TetraSpar prototype was not fully operational by the project completion. However, in lieu of full-scale test data, Stiesdal Offshore Technology completed wave-tank testing of a model-scale TetraSpar at the University of Maine's Harold Alfond W2 Tank in November 2018 through February 2019 and delivered the model properties and test data to NREL. Stiesdal also provided to NREL all of the data needed to build an OpenFAST model of the full-scale TetraSpar prototype, including Siemens 3.6-MW wind turbine, that was under construction during the execution of this project for the purposes of code-to-code verification.

An illustration of the TetraSpar, together with a picture of the TetraSpar model tested at the University of Maine, are shown in Figure 3.

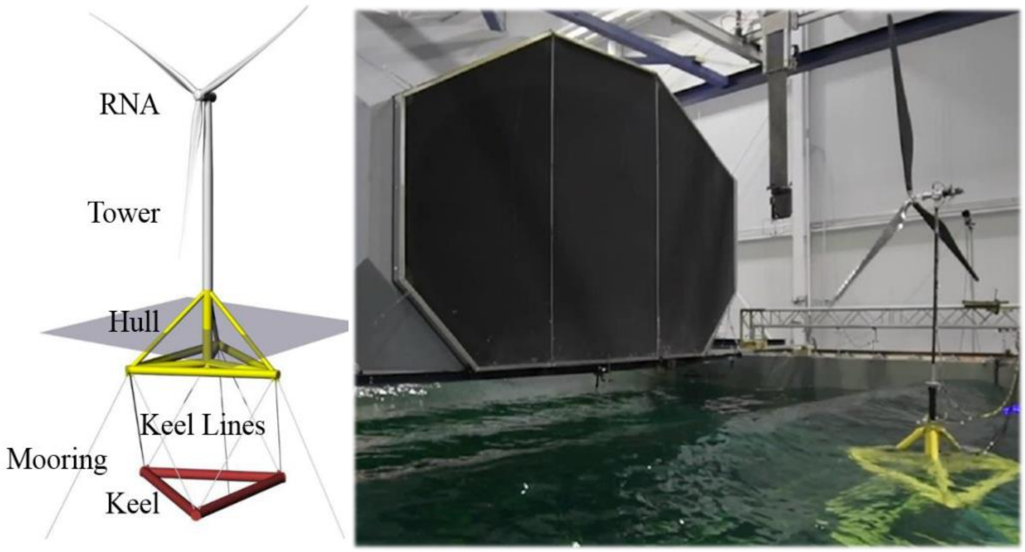

Figure 3: Illustration of the Full-Scale TetraSpar Prototype (Left) and Picture of the TetraSpar Model Tested at the University of Maine (Right)

NREL reviewed the wave-tank test data for applicability to model validation, including a thorough quality assessment of the model properties and test measurements. The as-built model is a 1:43 scale representation of the full-scale TetraSpar protype. The tower was modeled flexibly, but the rotor included structurally rigid blades. Two of the catenary moorings were truncated to fit in the wave basin. The test matrix included both wind and wave excitation, as well as many repeat tests. A summary of the test matrix is as follows:

- Wind and wave calibrations
- System identification tests, including
    - Static offsets
    - Free decay
    - Pink noise
- Operational at rated
- Operational at post-rated
- Idling during 50-year event
- Idling during 2,000-year event
- Idling during 50-year event, including a yawed condition.

Measurements during the tests included wind speed and wave elevation, platform six-degree of freedom motion (surge, sway, heave, roll, pitch, and yaw), fairlead tension in all three mooring lines, line tension in all six keel lines, and the tower-base moment. Apart from the keel lines, the model-scale TetraSpar hull was too stiff to obtain measurements of the loads within the braces or central column of the hull. Some of the tests were run without the measurement cable umbilical to determine the influence of the umbilical on the results. Some tests were also run with an augmented mooring system, in terms of a bridle to affect the yaw stiffness.

Overall, the dataset appears to be quite useful for model validation, including for some of the new capabilities of OpenFAST like the keel line tension, which was not previously possible to calculate from OpenFAST until the upgrades introduced in Task 2. However, the dataset is not without some issues, as summarized below:

- The draft (heave position) of the TetraSpar changed almost daily during the test campaign (with no explanation), so, the numerical model(s) to be validated would have to updated depending on the load case and there is some uncertainty in the heave measurement
- The surge free-decay is not useable due to the erroneous amplitude and frequencies obtained
- The hull motion for the operational at rated test appears to be corrupted.

Based on this data availability, NREL and Stiesdal Offshore Technology, together with Aalborg University who also works with Stiesdal, collaboratively developed a plan for verifying and validating the new OpenFAST functionality, including:

- Code-to-code comparisons of OpenFAST against OrcaFlex for a series of load cases using models of the full-scale TetraSpar prototype
- Code-to-data comparisons of OpenFAST against the wave-tank test data of the model-scale TetraSpar.

The results for the code-to-code verification are presented in Task 4.

Task 4: Verify and Validate the Upgraded OpenFAST Tool

To verify the new OpenFAST capability developed in Task 2, the results from OpenFAST were compared to results from OrcaFlex for a series of load cases using models of the full-scale TetraSpar prototype, including Siemens 3.6-MW wind turbine, based on the configuration properties obtained, and verification plan developed, in Task 3. Aalborg University, who works with Stiesdal Offshore Technology, built the OrcaFlex model and submitted OrcaFlex results. OrcaFlex is an industry-standard software for the dynamic analysis of offshore marine systems.

The full-scale models of the TetraSpar prototype were developed based on configuration properties provided by Stiesdal Offshore Technology in Task 3. Due to the complexities of the full-scale prototype, a few simplifications were made to facilitate the code-to-code verifications:

- The rotor-nacelle assembly of the Siemens 3.6-MW wind turbine with 130-m rotor diameter was modeled as a lumped mass and inertia because the focus of the verification was on the support structure
- Revolute joints in the TetraSpar were not modeled (it was intended to introduce these joints in some load cases, but these load cases were dropped due to a lack of time)
- Aerodynamic loads were precomputed from HAWC2 for a rigid system and applied to the OpenFAST and OrcaFlex models at the tower top as time-dependent applied forces and moments
- Hydrodynamic loads were derived from the undisturbed wave kinematics at the undisplaced position of the floater

- First-order wave theory without wave stretching was used[*]
- A strip-theory-only approach was used rather than a combined potential flow and strip-theory solution
- Simple hydrodynamic coefficients were prescribed (i.e., a drag coefficient of 0.6 and an added-mass coefficient of 1.0) rather than using coefficients calibrated against the wave-tank test data.

A series of load cases—outlined in —were set up and ran to enable the code-to-code verification. The cases include analysis of the static equilibrium condition, eigenfrequencies, and eigenmodes in the absence of wind and wave excitation; free-decay response; wind-only excitation in still water; wave-only excitation in still air; and combined wind- and wave-excitation.

[*]OrcaFlex cannot disable wave stretching, so, the resulting differences between OpenFAST and OrcaFlex were alleviated by setting the hydrodynamic coefficients above the still water to zero in OrcaFlex. Nevertheless, this difference in model set-up results in some of the differences in the code-to-code verification results.

Table 1: Load Cases for the Code-to-Code Verification

	Load Case	Enabled DOFs	Initial Conditions	Wind Conditions	Marine Conditions	Comparison Type
Static Analysis	1.1	Mooring lines, 6-DOF rigid body	None	None	Still water	Static response
	1.2	Mooring lines, 6-DOF rigid body, substructure, tower	None	None	Still water	Static response
Free-decay	2.1	Mooring lines, 6-DOF rigid body, substructure, tower	Surge = 10 m	None	Still water	Eigenfrequency and damping
	2.2	Mooring lines, 6-DOF rigid body, substructure, tower	Pitch = 5 deg	None	Still water	Eigenfrequency and damping
	2.3	Mooring lines, 6-DOF rigid body, substructure, tower	Heave = 5 m	None	Still water	Eigenfrequency, and damping
Eigen-analysis	3.1	Mooring lines, 6-DOF rigid body	None	None	Still water	Eigenfrequencies
	3.2	Mooring lines, 6-DOF rigid body, substructure, tower	None	None	Still water	Eigenfrequencies
Wind-Only	4.1	Mooring lines, 6-DOF rigid body, substructure, tower	None	Steady wind: Prescribed load time series at tower top V_{hub} = 9.00 m/s	Still water	Time series (t = 100 s)
	4.2	Mooring lines, 6-DOF rigid body, substructure, tower	None	Turbulent wind: Prescribed load time series at tower top V_{hub} = 12.91 m/s	Still water	Time series (t = 3600 s)
	4.3	Mooring lines, 6-DOF rigid body, substructure, tower	None	Turbulent wind: Prescribed load time series at tower top V_{hub} = 21.19 m/s	Still water	Time series (t = 3600 s)
Wave-Only	5.1	Mooring lines, 6-DOF rigid body, substructure, tower	None	None	Regular waves: H = 9.41 m, T = 14.3 s	Time series (t = 143 s)
	5.2	Mooring lines, 6-DOF rigid body, substructure, tower	None	None	Irregular waves: JONSWAP wave spectrum H_s = 7.1 m, T_p = 12.1 s, γ = 2.2	Time series (t = 3600 s)
	5.3	Mooring lines, 6-DOF rigid body, substructure, tower	None	None	Irregular waves: JONSWAP wave spectrum H_s = 10.5 m, T_p = 14.3 s, γ = 3.0	Time series (t = 3600 s)
Wind + Waves	6.1	Mooring lines, 6-DOF rigid body, substructure, tower	None	Steady wind: Prescribed load time series at tower top V_{hub} = 9.00 m/s	Regular waves: H = 9.41 m, T = 14.3 s	Time series (t = 143 s)
	6.2	Mooring lines, 6-DOF rigid body, substructure, tower	None	Turbulent wind: Prescribed load time series at tower top V_{hub} = 12.91 m/s	Irregular waves: JONSWAP wave spectrum H_s = 7.1 m, T_p = 12.1 s, γ = 2.2	Time series (t = 3600 s)
	6.3	Mooring lines, 6-DOF rigid body, substructure, tower	None	Turbulent wind: Prescribed load time series at tower top V_{hub} = 21.19 m/s	Irregular waves: JONSWAP wave spectrum H_s = 10.5 m, T_p = 14.3 s, γ = 3.0	Time series (t = 3600 s)

H: regular wave height; H_s: significant wave height; T: regular wave period; T_p: peak-spectral wave period; γ: peak-enhancement factor; V_{hub}: average hub -height wind speed; t: time

A small, but representative set of the results from the various load cases are presented next. Some of the results have the axis labels removed to protect confidential information.

There is good agreement between OrcaFlex and OpenFAST in terms of eigenfrequencies—see Figure 4. The natural frequencies were derived from a combination of modal analyses based on system linearization in OrcaFlex and a combination of modal analyses and time-domain simulations in OpenFAST. Some eigenfrequencies from OrcaFlex are in reality slightly different when post-processing the results from time-domain simulations.

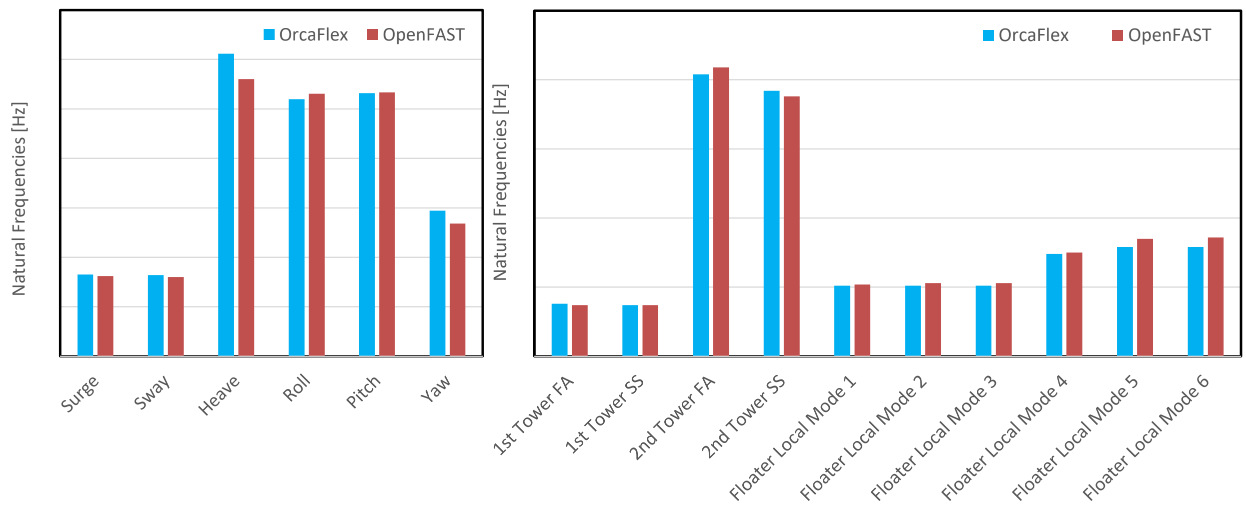

Figure 4: System Eigenfrequencies from Load Case 3.2

Good agreement is observed between OpenFAST and OrcaFlex for the different free-decay tests performed, as shown in Figure 5.

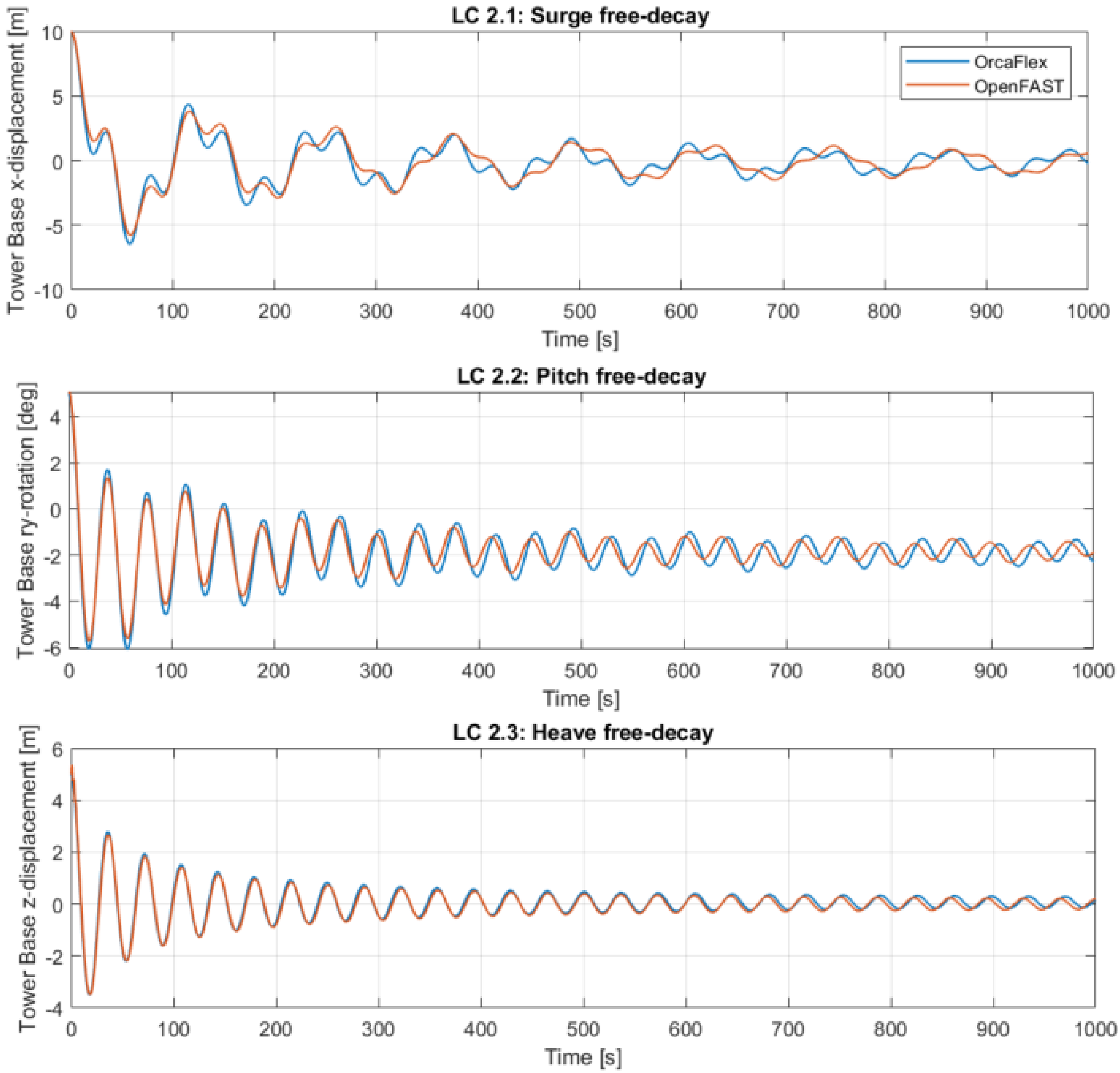

Figure 5: Free-Decay in Surge, Pitch, and Heave from Load Cases 2.1-2.3

Very good agreement is observed for the keel line tensions in the different load cases studied; for example, Figure 6 shows the keel line tensions from regular wave excitation in load case 5.1.

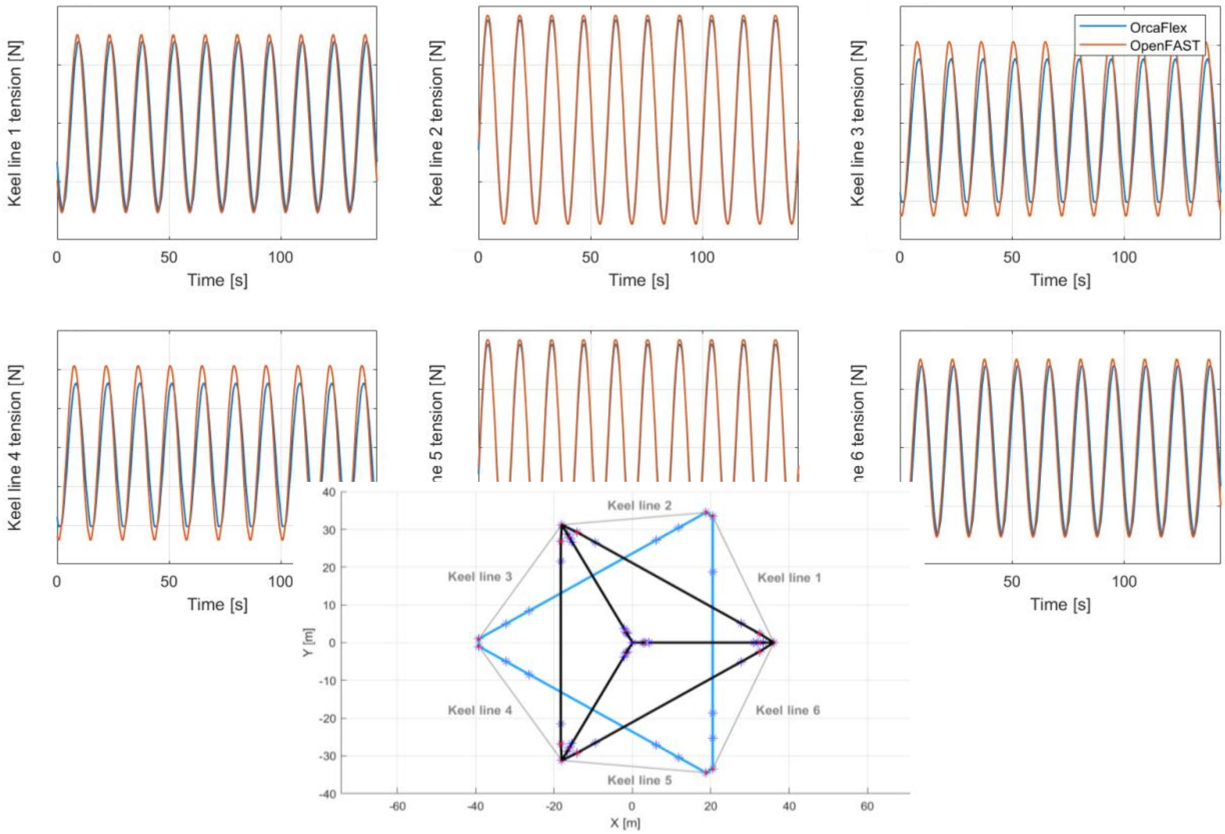

Figure 6: Keel Line Tensions Under Regular Wave Excitation from Load Case 5.1

Dynamic loads in the substructure were not easy to compare because the OpenFAST outputs from SubDyn do not include the damping contribution to the internal member-level loads, which are included in OrcaFlex; for example, Figure 7 shows the three reaction forces and three reaction moments at the tower base under regular wave excitation from load case 5.1. In this condition, the along-wave components of the forces (Fx, Fz, and My) are the only terms that are not close to zero; the mean loads for these terms generally agree very well between OpenFAST and OrcaFlex, but the oscillations about the means are impacted by the absence and inclusion of the damping contribution to the internal member-level loads.

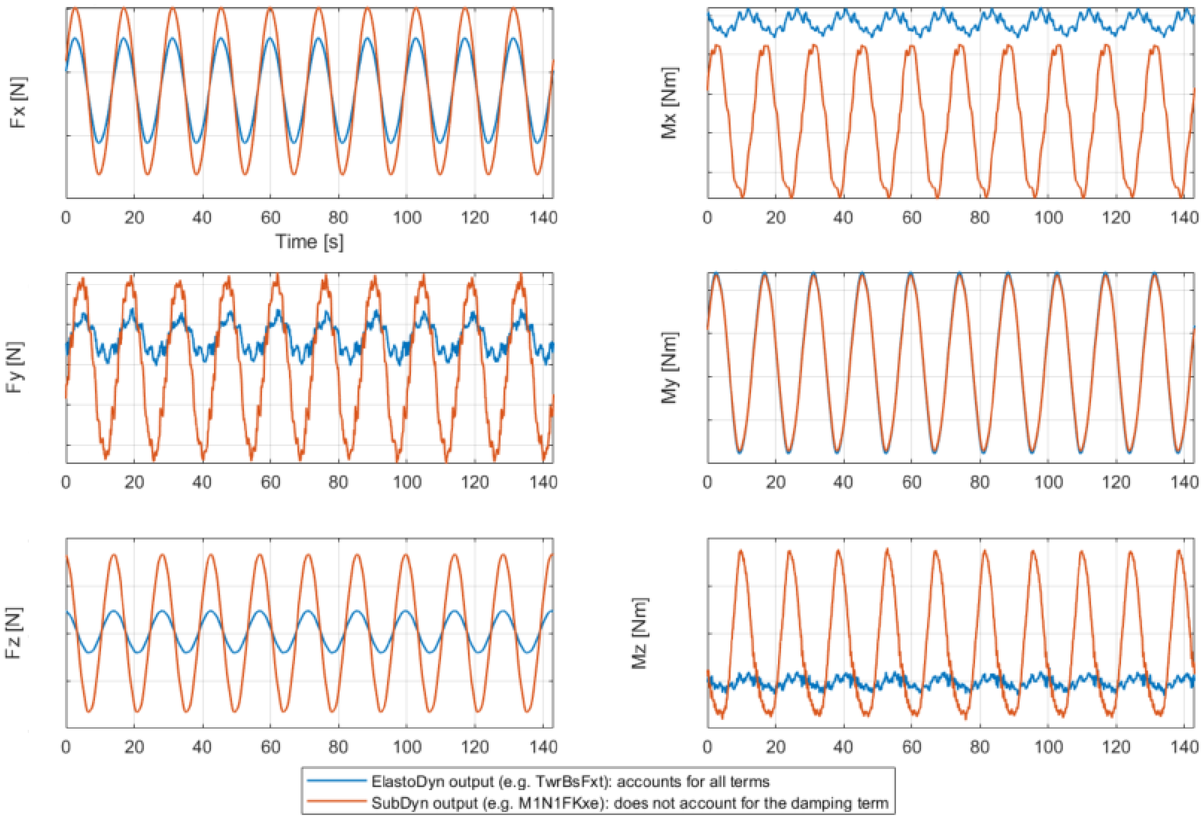

Figure 7: Loads at the Tower Base Under Regular Wave Excitation from Load Case 5.1

Figure 8 shows the internal bending moments in various members of the TetraSpar under regular wave excitation in load case 5.1. Internal bending moments in the radial brace 1 (RB1) and central column (CC) show good agreement between OrcaFlex and OpenFAST. However, the agreement for the diagonal brace 1 (DB1) and lateral brace 1 (LB1) locations is not as good. Before this project, the internal member-level load could not be calculated by OpenFAST.

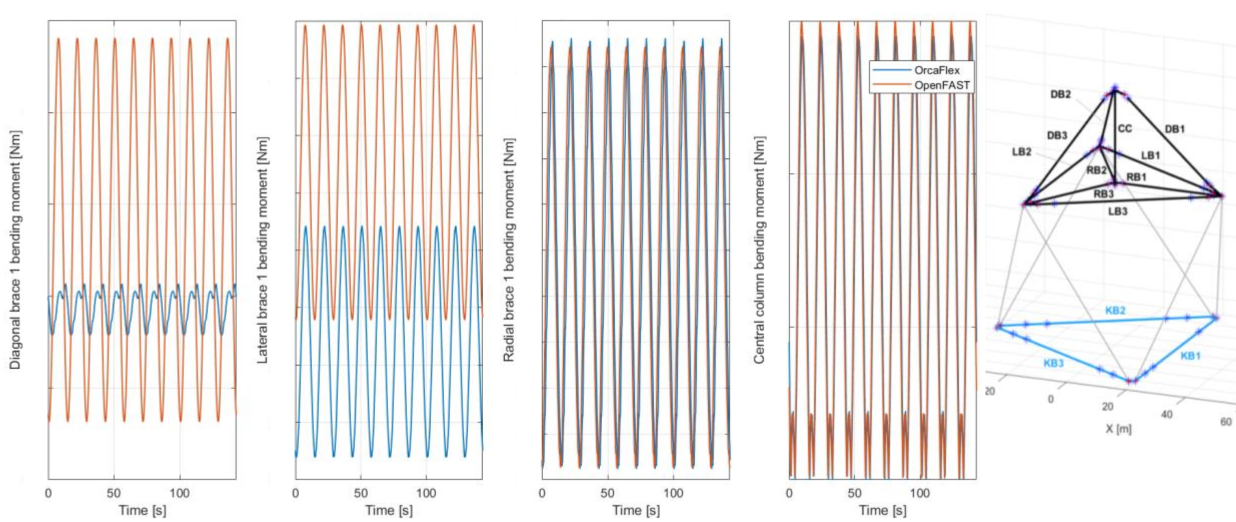

Figure 8: Bending Moments in Various Members of the TetraSpar Under Regular Wave Excitation from Load Case 5.1

The mooring line tensions calculated by OpenFAST and OrcaFlex generally agree very well, but OpenFAST experiences some slack events not observed in OrcaFlex—for example, see Figure 9. The reason is not yet known, although slack events are seen in OrcaFlex under more severe conditions. For reference, the agreement for the system motion (e.g., tower base location) is excellent between OrcaFlex and OpenFAST, also shown in Figure 9.

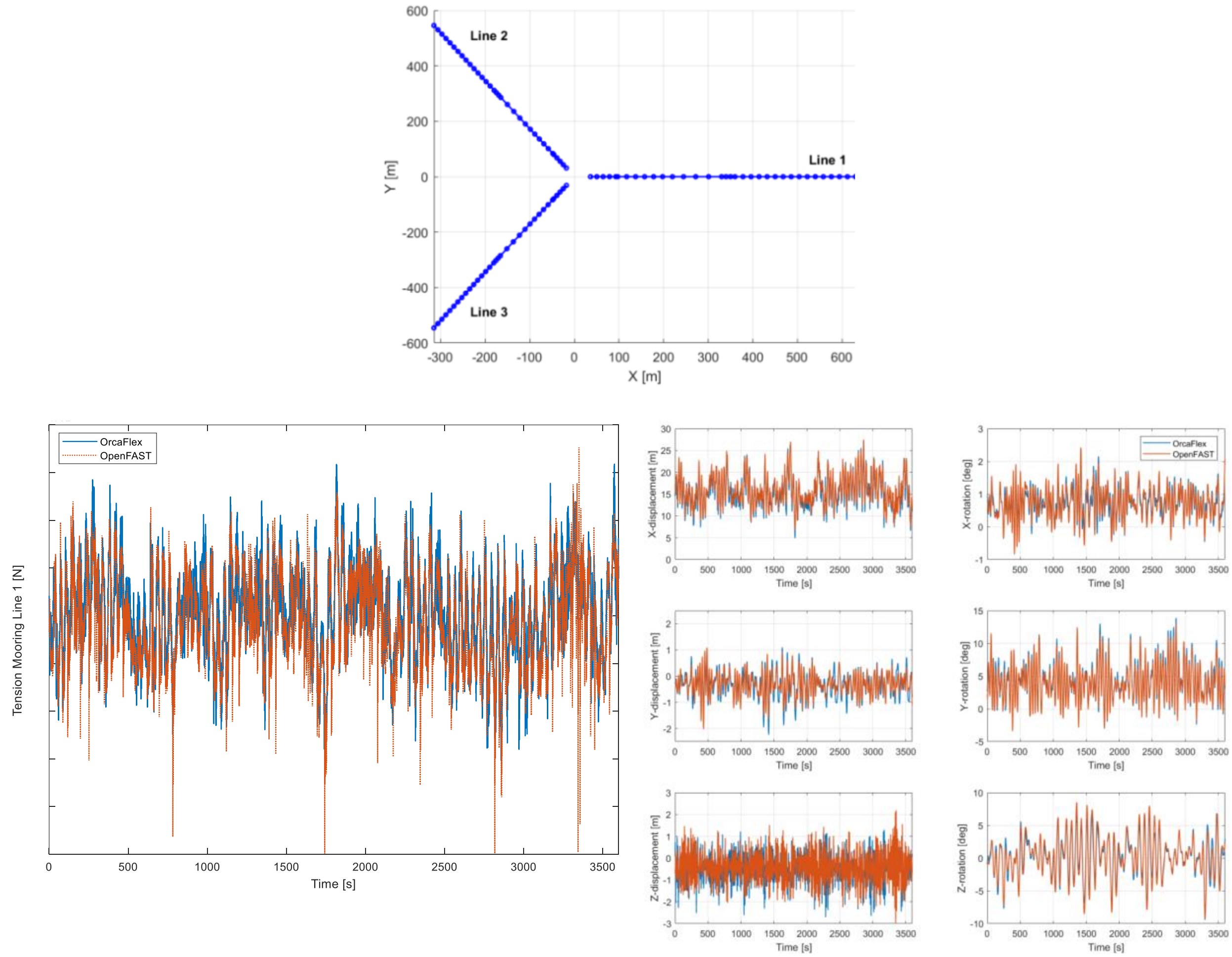

Figure 9: Mooring Line Tension (Left) and Tower-Base Motion (Right) Under Turbulent Wind and Irregular Wave Excitation from Load Case 6.2

The tower-base loads generally match very well across the range of excitation frequencies from turbulent wind and irregular waves. However, around the tower natural frequency, OpenFAST has unexpectedly higher damping, which can be observed in the frequency domain when post-processing the time domain data, as shown by the power spectral density (PSD) of Figure 10.

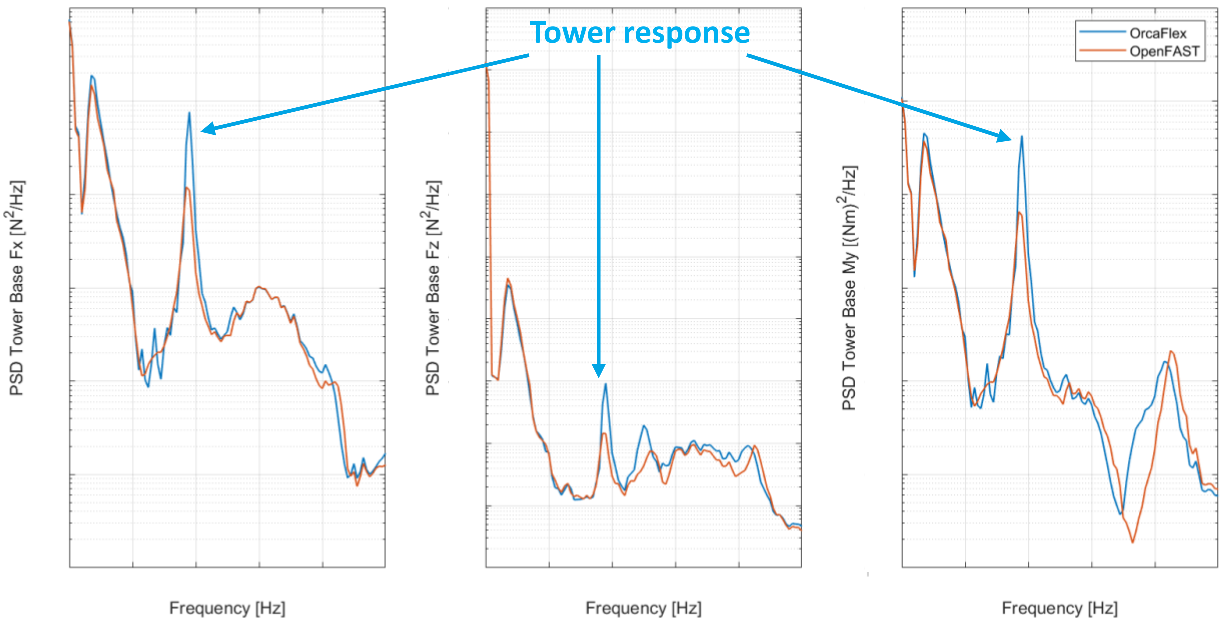

Figure 10: Power-Spectral Density (PSD) of the Tower-Base Loads Under Turbulent Wind and Irregular Waves from Load Case 6.3

The verification of the upgraded OpenFAST tool against OrcaFlex using the models of the full-scale TetraSpar prototype was presented at WESC 2021.

An OpenFAST model of the model-scale TetraSpar suitable for validation of OpenFAST against the wave-tank test data from the University of Maine was also assembled, based on the configuration properties obtained in Task 3. The OpenFAST model was made as a full-scale equivalent because the wave-tank test data was scaled up to full scale. The code-to-data validation of OpenFAST based on the wave-tank data was initiated, but was not completed by the conclusion of the project. The intent of the originally proposed validation work will be completed in follow-on projects such as the IEA Wind Task 30 OC6 Phase IV and the ARPA-E ATLANTIS programs.

Task 5: Advance the Technology Readiness Level of the TetraSpar

This task was dropped during the project rescoping and no work was completed. Since the CRADA was written, Stiesdal Offshore Technology improved their internal modeling capability and have performed loads analysis, rendering this task less important for Stiesdal anyway.

References:

[1] Jonkman, J. M.; Damiani, R. R.; Branlard, E. S. P.; Hall, M.; Hayman, G. J; and Robertson, A. N. "Substructure Flexibility and Member-Level Load Capabilities for Floating Offshore Wind Turbines in OpenFAST." *American Society of Mechanical Engineers (ASME) 2nd International Offshore Wind Technical Conference (IOWTC2019), 3–6 November 2019, St. Julian's, Malta* [online proceedings]. URL: https://asme.pinetec.com/iowtc2018/data/pdfs/trk-1/IOWTC2018-1025.pdf. IOWTC2019-7566. Houston, TX: The American Society of Mechanical Engineers (ASME International) Ocean, Offshore and Arctic Engineering (OOAE) Division, November 2019; NREL/CP-5000-74380. Golden, CO: National Renewable Energy Laboratory.

[2] Jonkman, J; Branlard, E.; Hall, M; Hayman, G.; Platt, A.; and Robertson, A. *Implementation of Substructure Flexibility and Member-Level Load Capabilities for Floating Offshore Wind Turbines in OpenFAST*. NREL/TP-5000-76822. Golden, CO: National Renewable Energy Laboratory, August 2020.

Subject Inventions Listing:

None

ROI #:

None